NBSIR 81-2391 (R)

# Technical Activities 1981 Center for Absolute Physical Quantities

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

November 1981



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# TECHNICAL ACTIVITIES 1981 CENTER FOR ABSOLUTE PHYSICAL QUANTITIES

Karl G. Kessler, Director

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Prepared for:
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**U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige,** ***Secretary***
**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 1981 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.

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Part II

# INTRODUCTION

This book is Part II of the 1981 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, 1980 to September 30, 1981. The Center is one of the five resources and operating units in the National Measurement Laboratory.

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

More information about particular work may be desired. To obtain this, the reader should address the individual scientists or their division, c/o Center for 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 1981

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

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

Submitted

G. Mehlman, J.W. Cooper and E.B. Saloman, "The Absolute Photoabsorption Cross Section of the K Shell of Atomic Lithium," Phys. Rev. A.

### COMMITTEE MEMBERSHIPS

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

K. G. Kessler, Chairman, Committee on Optical Fiber Communication Journal, Optical Society of America.

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.

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

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QUANTUM METROLOGY GROUP

SUMMARY OF ACTIVITIES

FISCAL YEAR 1981

## I. OVERVIEW

The year just past was one involving both temporary arrangements and appreciable change. R. Deslattes was largely absent while serving as Director of NSF's Physics Division. Various patterns of periodic and continuous contact were attempted through the year. Main management responsibility fell to E. Kessler while J. Snyder was assigned interim responsibility for work in the gravity and laser areas.

Work in the Quantum Metrology Group remains diverse but is of diminishing range owing to staff reduction, loss of a hire-in-progress and lowered expectations. Efforts in the area of spectra from laboratory and astrophysical plasmas have been terminated (with loss of one staff person) except for a small, short-term guest worker manned project to complete an externally funded study of laser produced plasmas. In the area of laser spectroscopy of H and He, a planned new hire was halted by the inauguration, a staff member was eliminated by the RIF procedure, and a part-time person is on extended leave-without-pay. The one remaining staff person in this general area (Snyder) has been involved in the development of radiofrequency and laser wavelength measurement technology. Scientific opportunities which led to the laser effort remain valid while it is still to be seen whether a future regeneration becomes possible.

As will be described in more detail below, the Gravitational Constant work of Luther (NBS) and Towler (University of Virginia) has come to a terminus of sorts. They have succeeded in obtaining a significant new result on "G" but without exploiting the "Beams" method on which our work has been alleged to be based. Instead, the publishable material from this long effort represents a repetition of the "perturbed period" work of Heyl and Heyl and Chrzanowski. Given present austerity, it seems inappropriate to give further work in this direction high priority. Such a termination is mildly unfortunate from an aesthetic point of view but probably not otherwise serious. Related work on ancillaries for gravitational radiation experiments and on the conceptual limits of measurement will probably continue at a low level in the former case and with the aid of a retired guest worker in the latter.

The remaining efforts of the Group fall into the areas of X-ray spectroscopy and precision measurement in the $\gamma$-ray and X-ray regions. These efforts have enjoyed better support, more noticeable output and less personnel attrition; they are nonetheless not free of problems and constraints. In the area of qualitative spectroscopy, we had a singularly successful run at the Stanford Synchrotron Radiation Laboratory early this summer which is still to be put in publishable form. Our main effort focusses on preparations for experiments at Brookhaven's National Synchrotron Light Source (NSLS). Our work, to which P. Cowan has been the principal contributor, goes more slowly than desirable but is not behind other comparable efforts and work on the NSLS itself.

The main area in which one can see continued technical growth, good results and outstanding future opportunities is that of precision X-ray and $\gamma$-ray studies. The principal person involved is E. Kessler, who was joined this past year by Dominique Girard who came as a guest worker under CNRS sponsorship. Among accomplishments to date one finds new results on pion and kaon masses, tests of QED in muonic atoms and of relativistic SCF calculations in normal atoms. There is an approved $\gamma$-ray experiment at Grenoble and a proposal (jointly with Oxford) for work on stripped atom X-rays at Darmstadt. There is a successful double flat crystal Van de Graaff program at completion and a newly commissioned 4 meter DuMond instrument. There is even controversy since our colleagues at PTB have this year succeeded in an independent X-ray/optical interferometer measurement of a Si crystal that appears discrepant with ours from long ago. This needs investigation and understanding since it underlies our entire measurement chain from the visible to $\gamma$-ray region.

## II. TECHNICAL ACTIVITIES

### 1. X-ray Diagnostics of Laboratory and Astrophysical Plasmas
A. Burek

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 instrument design and crystal utilization. We provide state-of-the-art calibration to help secure maximum scientific return and explore new approaches including development of geometries and diffraction systems having characteristics not available otherwise.

Current Activities

Effort in this area was prompted by a contract from NASA via Lockheed 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 worked with the SMM team on various aspects regarding the applications of crystal calibration to the analysis of data. These activities involved 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. As part of a Guest Investigator Program funded by NASA, an observing program was defined and incorporated in the mission 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 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. The compilation and extension of this data is being prepared for publication.

We pursued the development of novel crystal dispersing elements and devoted some time to the problem of fabricating large lithium fluoride panels for a space experiment. We also investigated 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.

Finally, a proposal to DOE for the development of efficient crystal spectrometers and X-ray interferometers for inertially confined plasma studies was funded. Although planning and crystal calibration have occurred, the work is being transferred to the University of Rochester due to a reduction-in-force.

## 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. A paper applying X-ray calibration techniques to the analysis of high resolution solar X-ray data has been published in the Astrophysical Journal.

Preparations for X-ray diagnostics of laboratory plasmas have been made.

## Future Plans

Because of reduction in staff, all work on X-ray diagnostics of laboratory and astrophysical plasmas has been discontinued.

2. Optical Physics
   J. Snyder, H. Holt (60%)

Objectives

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

Current Activities

The experimental collaboration with the Molecular Spectroscopy Division in the Center for Chemical Physics continues, albeit slowly because of the increased administrative responsibilities of the collaborators. This situation has eased recently, and we hope for a more active program in the coming year. The collaboration involves the application of recently developed techniques for high-sensitivity saturated absorption spectroscopy to the systematic study of simple molecules using a tunable cw dye laser. The new wavelength-measuring technology will also be of major importance in this work.

The original Fizeau Wavemeter is currently being used to evaluate the long-term instrumental accuracy, and to further improve the software. This instrument is also seeing occasional use for measuring wavelengths in some experimental studies in the Molecular Spectroscopy Division.

A second Fizeau Wavemeter is presently under development for eventual use in a collaborative effort at the University of Maryland. This instrument will be used on-line to determine the wavelength of coherent uv light generated by mixing tunable pulsed dye laser radiation with quadrupled YAG radiation. It is optimized for pulsed applications, and has been configured for easy interfacing with any small computer. A guest worker from the University of Maryland has been working here on the new instrument since spring. At the present time, construction of this Wavemeter is complete, and we are in the midst of calibrating the instrument against a uranium hollow cathode spectrum.

Work on a third Wavemeter has been initiated in collaboration with the Instrument Development Group of the Center for Analytical Chemistry. This device is being interfaced to an 8-bit microprocessor instead of to a 16-bit minicomputer as had been previously done.

A hybrid prototype of the Frequency Meter which uses a digital filter technique to increase the resolution of a frequency measurement is being tested in use with Michelson-type laser wavelength meters ("Lambda Meters"). These tests involve collaborations with JILA and the Time and Frequency Division in Boulder, and with the Molecular Spectroscopy Division in Gaithersburg. The major effort at the present time is in improving the optics of these interferometers in order to be able to effectively utilize the resolution enhancement.

Our theoretical program is currently inactive due to illness of the principal investigator.

Accomplishments

Initial tests of the modified Fizeau Wavemeter were successful and were reported at the Los Alamos Conference on Optics. The instrumental accuracy is now believed to be close to one part in $10^{-7}$ (the design goal), and is presently limited by the accuracy of available references. The Wavemeter was successfully converted to interface directly with a small lab minicomputer which has been configured to simultaneously scan the laser, measure the wavelength, and record up to 16 channels of input data. This system has seen some limited use in studies of opto-galvanic spectra.

A second Wavemeter for use in a collaborative effort with the University of Maryland has been constructed and is being calibrated.

A second company has applied for a license from NTIS to market the Fizeau Wavemeter.

The new Frequency Meter has been analyzed in detail and was described at the 35th Annual Frequency Control Symposium. Further analysis by Allan and Barnes (Time and Frequency Division), showing that the Frequency Meter algorithm can improve the characterization of precision oscillators, was also presented at the Symposium. The adoption of a "modified Allan Variance" incorporating the Frequency Meter algorithm was suggested.

The hybrid prototype of the Frequency Meter was tested on the 3-meter JILA Lambda Meter. An improvement in the numerical resolution of the wavelength measurement by a factor of 100 was achieved and reported at CLEO.

Future Plans

An experimental plan to investigate methods for generating so-called "squeezed states" with reduced shot noise has been proposed. If approved and supported, we expect to begin this program during the coming year.

The collaboration with the Molecular Spectroscopy Division will continue at a higher level. Our intention is to study the spectra of simple molecules.

The hybrid Frequency Meter has proven its effectiveness, but it is still too slow and too dependent on a computer. An all-digital-hardware instrument with substantially greater speed and reduced computer dependence will be built and tested.

The new Frequency Meter will be used in the continuing collaboration at JILA to increase the accuracy of interferometric wavelength comparisons. We expect to achieve numerical resolution near $10^{-12}$, and accuracy possibly approaching $10^{-11}$ if the optical problems can be sufficiently reduced.

Additional effort involving the new Frequency Meter will concentrate on increasing the accuracy and read-out speed of conventional Lambda Meters, and on the development of a new compact Lambda Meter with a total motion of 1 cm. This new Lambda Meter is expected to achieve accuracy near $10^{-8}$ in wavelength comparisons.

3. One- and Two-Electron Spectra
K. Harvey

Objectives

This program was primarily concerned with fundamental experimental studies of simple atomic systems. We had hoped to expand this program through an additional slot made available to us by NML last year. The expansion slot was lost during the course of the presidential hiring freeze last winter, and the program has now been effectively closed down by the recent loss of its primary investigator.

Accomplishments

The hydrogen metastable atomic beam chamber, which has been the focus of most of the effort in this program for several years, was tested and achieved modest flux levels during the past year. Details of its design and operation are in press. Further work in the apparatus has been halted pending a decision on future research directions in the Group.

The investigation of the thermionic diode was completed and the results published. This device received an IR-100 Award this year.

4. Gravity
G. Luther, W. Towler (IPA)

Objectives

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

Current Activities

A new and metrologically amenable test mass for the "G" measurement is now being constructed. It is hoped that this mass will contribute negligibly to the uncertainty of the final measurement. The symbiotic relationship between torsion fibers and the measurement of the Newtonian Gravitational Constant goes back several hundred years. While the new bob is being constructed, the apparatus is being used and the data are being taken in order to analyze, in exquisite detail, the characteristics of torsion fibers made of several different materials (quartz, tungsten, graphite).

Accomplishments

The data taken in the past year has been reduced, big "G" has been calculated, and the value determined was reported at the Second International Conference on Precision Measurements and Fundamental Constants. The uncertainty in this measurement, 64 ppm, compares quite favorably with the previously accepted CODATA value which had an uncertainty of 615 ppm. A more powerful computer, an Interdata 7/16, was mated to the experiment in place of the old reliable Model 70. The capability of storing data directly on floppy discs is now available, and the NBS Bus associated with the new computer allows the creation of a software up/down counter to encode the position of the table. Initial measurements of the new pieces of apparatus indicate that we may yet be able to improve the precision of the measurement by a factor of two or three (about 30 ppm).

Future Plans

A final assault on the value of "G" is being mounted. The base camps have been set up and the routes of climb have been surveyed. Data shall be taken at two positions of the large mass system allowing the radial variation of "G" or lack thereof to be determined with sufficient accuracy to decide the value of some of the current theories.

5. Fundamental Theory
R. Hayward (Guest Worker)

## Objectives

The gravitational interaction is the only one of the four fundamental interactions (strong, electromagnetic, weak, and gravitational) in which no dynamical effects have been quantitatively measured. It is the purpose of this theoretical investigation to assess those features that are in common with the gravitational and the other interactions that may present possibilities for experiment.

## Current Activities

The theoretical effort for the past few years has been concerned with the study of experimental measurements at the quantum level with the purpose of determining the ultimate limits of precision of the measurement which may be the deciding factor in the detection of gravitational radiation. A scientific paper on this study is in press. As yet, no experiment has reached the quantum level where these results may be tested.

The geometrical interpretation of general relativity has often obscured certain physical features that might be more recognizable if the theory were formulated in an equivalent, but more familiar format, a wave equation form. Such a formulation has been undertaken during the past year.

## Accomplishments

A matrix formulation of general relativity has been accomplished, writing a Dirac type wave equation for the fields of general relativity. We use a representation of multicomponent four vector wave functions, rather than the "twistor" fields of Penrose. This is a gauge invariant theory, in which all features of general relativity may be generated by commutation relations amongst the fields and operators. The one to one homomorphism between the four vector fields and the coordinates, and also, the non-Abelian character of the interaction allows the equivalent geometrical interpretation. A scientific paper reporting these results is in preparation.

## Future Plans

An effort will be made to second-quantize these fields of general relativity and to develop a straightforward field theory of gravitation in analogy with that of quantum electrodynamics.

6. X-ray Spectroscopy - Synchrotron Radiation
P. Cowan, R. LaVilla, A. Henins (1/2), T. Jach (1/2)

## Objectives

This longstanding effort aims toward elucidation of some of the finer details of X-ray spectra from atoms, molecules and simple solids. The more interesting features of atomic X-ray spectra involve aspects such as those due double vacancy processes which are unaccounted in a single vacancy, active electron approximation. Such features are ubiquitous contaminating and often rendering uninterpretable spectra from aggregate systems. Preliminary results already obtained from a storage ring source validate our strategy for untangling this complex phenomenology.

## Current Activities

Our work is in a transitional phase as annual runs at Stanford Synchrotron Radiation Laboratory (SSRL) will be replaced by almost continuous operation at the National Synchrotron Light Source (NSLS) at Brookhaven. We have maintained and expect to continue to maintain a strong in-house X-ray spectroscopy program both as a support base for the offsite work and because many questions can still be most effectively studied by conventional means. The next few paragraphs attend in order to the home laboratory, the SSRL work presently closed and the NSLS effort which is under construction at present and hopes to begin operation by mid 1982. A miscellany of other work at accelerators, LURE (Orsay), and SURF-II (NBS) will not be emphasized.

The home laboratory is well instrumented for general X-ray spectroscopy. Its main apparatus centers on a vacuum double crystal spectrometer which though launched over 18 years ago remains world-class. This state of affairs was helped by major recent renewal which gave it a new highly stabilized power source, a CAMAC based control system and a pair of high performance angle encoders. Requests for time on this facility have been plentiful including major periods of operation for calibration of space instrumentation. All crystals processed for these purposes are now in earth orbit and the program terminated (see 1). Main applications otherwise during the past year included: 1) acquisition of a detailed reference spectrum in support of the SSRL Argon experiment; 2) Burek used instrument from part of December to near end of February studying crystals but mostly doing Fraenkel's measurement on double diffraction. Unfortunately a substantial effort was required for installing and debugging the new power source. In the immediate future it will be applied to determining Bismuth $M_V$ absorption profiles for a TRIUMF measurement of the $\pi$-d strong interaction shift. It will also be applied to the first precision determination of the Xe L emission spectrum as part of the precision X-ray program (see 7).

## Accomplishments

During the year we had another run at SSRL, that was very successful in contrast to the previous July 1980 run. We obtained: 1) a more complete set of data in the K$\beta$ region including variation of the resonant-Raman, Rayleigh, and intensity profile changes of the K$\beta_{1,3}$, $\beta'$ and $\beta''$ group with incident photon exciting energy; 2) an experimental measure of the contribution of the K$\beta$ intensity due to higher harmonics; 3) a detailed absorption measurement of the double excitation 1s3p feature which shows a Fano line shape; 4) the detection and measurement of the 1s2p double excitation threshold of argon; 5) the extension of these double differential measurements to a preliminary study of the K$\alpha$ region of argon; 6) data was taken to obtain an experimental partial cross-section for the double vacancy feature $\alpha_{3,4}\alpha'$; and 7) the K$\alpha_{1,2}$ profile and the resonant-Raman scattering feature were studied for different photon excitation energies close to the 1s threshold.

## Future Plans

For the future we anticipate a dedicated beam line at NSLS equipped with UHV high resolution primary crystal monochromator and secondary monochromators for photons and electrons. Conceptual design is far advanced, all major external procurements are complete, a prototype double crystal monochromator (designed by P. Cowan) has been built and operated at the Cornell facility, CHESS. (Cowan's design is sufficiently attractive that we have been asked to consider furnishing a total of five to equip the facility beam lines and two other user groups.) Our overall system will be one of both very large scale ($\sim$ 25 meters from tangent point to target area) and extraordinary complexity. The double crystal monochromator will be preceeded by a grazing incident collimating mirror and followed by a refocussing mirror. Target chambers will have facilities for both gas and solid samples and be equipped with imaging X-ray and electron spectrometers. Initial assembly of beam line components should be in progress at the time of the Panel meeting with production machining of the final system about to begin.

7. Precision X-ray and $\gamma$-ray Measurements
E. Kessler, D. Girard (GW), and A. Henins (1/2)

## Objectives

The objective of this project is accurate wavelength standards in the 20 keV to 5 MeV region. The standards are related to visible wavelengths and the Rydberg, $R_\infty$, through the X-ray/optical interferometry measurement of the lattice spacing of a silicon crystal. The standards which have been measured include: a) X-ray transitions which are used for testing relativistic self-consistent field calculations, b) $\gamma$-ray transitions which are used for calibrating bent crystal spectrometers and Ge detectors used in mesic X-ray work, and c) absorption edge determinations used in kaonic X-ray measurements. The targeted accuracy is 0.1 to 1 ppm for $\gamma$-rays, a few ppm for X-rays, and 15 ppm for edge measurements.

Precision $\gamma$-ray wavelengths have the potential of contributing to the fundamental constants. The recent interest is in the mass-wavelength conversion factor which can be obtained by combining wavelength measurements of capture $\gamma$-ray cascades with mass spectroscopy measurements of the associated mass differences.

## Current Activities

Three facilities exist for precision X-ray and $\gamma$-ray wavelength measurements. The two older facilities which have had extensive use are both double axis flat crystal spectrometers equipped with angle measuring interferometers. One of the instruments is located at the NBS reactor (primarily $\gamma$-ray measurements) while the other is located at the Radiation Physics Building (primarily X-ray measurements). The efficiency of these flat crystal spectrometers is a few x $10^{-11}$ so that only very intense lines can be measured. The third facility is a DuMond type curved crystal spectrometer and is just now becoming operational. The spectrometer has an estimated efficiency $\sim 10^3$ greater than the flat crystal spectrometers and is thus better suited for weak lines. Its targeted accuracy is 1 ppm.

X-ray measurements at the flat crystal facility located in the Radiation Physics Building have been the main activity during the past year. The principal researchers are E. Kessler and D. Girard, a guest worker. Here high Z K series X-rays are produced by electron bombardment using the 4 MeV electron Van de Graaff. We have completed measurements on the $K\alpha_1$, $K\alpha_2$, $K\beta_1$, $K\beta_3$ lines from Ag, Xe, Ba, Nd, Sm, Er, W, Au, Pb, Th and U. Our measurements are compared to theoretical self-consistent field calculations in order to illuminate deficiencies in our theoretical understanding of atomic energy levels. Our measurements have been one of the main stimuli which have prompted several theoretical groups to reconsider their calculations during the past year.

We have contributed to a new measurement of the mass of the kaon which was published during the past year. Our part of this work was the measurement of the K absorption edge of metallic Er foils ($E \sim 57.5$ keV) which had been used in a critical absorption measurement of kaonic potassium X-rays. Although the resulting mass value is less accurate (by a factor of 3) than the currently accepted value, it does eliminate concern about high order radiative terms.

The curved crystal spectrometer was transferred to NBS from the University of Colorado cyclotron. It has been upgraded during the past year by A. Henins, with considerable help from E. Kessler and D. Girard by: 1) installing precision angular contact bearing on the axis, 2) installing a low friction ball screw drive, 3) equipping the axis with an angle measuring interferometer, and 4) bending a high quality crystal to a radius of four meters. This spectrometer which is being brought into operation by Kessler and Girard with some help by Henins, is located at the 4 MeV electron Van de Graaff. It will be first used to study satellite lines from high Z K series X-rays. Previous measurements on hyper satellite lines (double K vacancies) from heavy elements have differed by more than three standard deviations from theoretical calculations and we hope to shed some light on this controversy.

During this past year, colleagues at PTB in Germany have published an independent X-ray/optical interferometer measurement of a Si crystal which is 1.8 ppm smaller than the value Deslattes and Henins published 5 years ago. This difference is considerably larger than what is expected because of variations in Si. We have interchanged Si samples with PTB and are currently comparing the PTB and NBS Si samples (Henins). Preliminary results appear to be troubled by surface effects, but show less than 1 ppm difference in the two samples. A thorough investigation of this discrepancy is underway.

Accomplishments

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

The results of the kaon mass experiment (Er K edge measurement) have been published.

A significant number of high Z X-ray lines have been measured and the results made available to theorists as a way of stimulating more accurate calculations. A manuscript on this work is in preparation.

Only one staff member (Kessler) works full time in this project. The absence of Deslattes has meant that a significant part of Kessler's time had to be devoted to administration. The accomplishments in this area during the past year have been affected by Deslattes being on leave.

## 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. The Institut Laue Langevin (ILL), Grenoble, France, has a high flux reactor with source manipulation capability. We have submitted a proposal to ILL and have received approval to place a flat crystal spectrometer at their reactor. Funding from NBS and the assignment of staff to this measurement are awaited.

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 $^{110m}Ag$ 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. An example of such a region is around 18 keV in which the end point of the β spectrum of tritium is located. A precision measurement of this end point is a potential test of the non-zero mass of the neutrino.

## INVITED TALKS

### Quantum Metrology Group - 520.06

E. G. Kessler, Jr., "Absolute X-ray and γ-ray Wavelength Measurements at the National Bureau of Standards - Their Application in Physics", November 18, 1980, at Institut Laue Langevin, Grenoble, France, and on November 21, 1980, at Studiecentrum Voor Kernenergie, Katholieke Universiteit, Leuven, Belgium.

R. D. Deslattes, "Inner Shell Energies: Experimental Problems", December 4, 1980, at the Workshop on Foundations of Relativistic Theory of Atomic Structure, Argonne National Laboratory, Argonne, Illinois.

P. L. Cowan, "The X-ray Standing Wave Method for Structure Determination: Applications in Surface Science", February 6, 1981, at Sandia Laboratories, Albuquerque, New Mexico.

J. J. Snyder, "A Novel Ultra-High Resolution Frequency Meter: Applications and Implications", February 10, 1981, at Center for Absolute Physical Quantities Colloquium, at NBS, Gaithersburg, Maryland, and on February 24, 1981, at Physics Department Colloquium, University of Virginia, Charlottesville, Virginia.

R. D. Deslattes, "Gamma-ray Secondary Standards: An Exercise in Precision Metrology with Application to Basic Standards", March 16, 1981, at Physics Division Colloquium, at the National Research Council, Ottawa, Canada.

J. J. Snyder, "Fizeau Wavemeter", April 7, 1981, at Conference on Optics '81 - Optics in Energy, at Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

J. J. Snyder, "Frequency Offset Saturation Spectroscopy", April 9, 1981, at Physics Department Colloquium, Los Alamos Scientific Laboratory, Los Alamos, New Mexico.

R. D. Deslattes, "X-ray Spectra of Normal and Exotic Atoms", April 27, 1981, at Physics Department Colloquium, University of Notre Dame, Notre Dame, Indiana.

J. J. Snyder, "An Ultra-High Resolution Frequency Meter", May 27, 1981, at 35th Annual Frequency Control Symposium, Philadelphia, Pennsylvania.

J. J. Snyder (co-authors: T. Baer and L. Hollberg (JILA); and J. L. Hall (525)), "Lambda Resolution Enhancement Using a Novel Frequency Meter", June 12, 1981, at Conference on Laser Electro-Optics, Washington, D. C.

PUBLICATIONS

Quantum Metrology Group - 520.06

D. Bloch, R. K. Raj, and J. J. Snyder, "Heterodyne Detection of Phase-Conjugate Emission in an Ar Discharge with a Low-Power cw Laser," J. Physique-Lettres 42, L31-L34 (15 January 1981).

A. J. Burek, D. M. Barrus, R. L. Blake and E. E. Fenimore, "Analysis of Solar X-ray Emission Line Profiles," Astrophysical J. 243, 660-676 (1981).

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J. J. Snyder, "Fizeau Wavemeter," Proc. of Conference on Optics '81 - Optics in Energy, Los Alamos, New Mexico, April 7-10, 1981.

J. J. Snyder, "An Ultra-High Resolution Frequency Meter," Proc. of the 35th Annual Frequency Control Symposium, May 27-29, 1981, Philadelphia, PA.

Richard D. Deslattes, "Applications of X-Ray Interferometry," Proc. of Second International Conference on Precision Measurement and Fundamental Constants, Gaithersburg, MD, 7-12 June 1981.

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SEMINARS FOR STAFF AND GUESTS

Quantum Metrology Group - 520.06

W. A. M. Blumberg, Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, Massachusetts - CAPQ Colloquium, "Laser Photodetachment Spectroscopy of Negative Ions in a Magnetic Field", November 18, 1980.

R. L. Panock, Bell Labs, Holmdel, New Jersey - CAPQ Colloquium, "Experimental Studies of Rydberg States of Atomic and Molecular H Helium", December 18, 1980.

T. Baer, JILA, Boulder, Colorado - CAPQ Colloquium, "Coherent Transient Spectroscopy of Hf with an F-Center Laser", January 22, 1981.

C. M. Caves, W. K. Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California - CAPQ Colloquium, "Quantum-Mechanical Noise in an Interferometer", January 23, 1981.

R. D. Knight, Center for Astrophysics, Cambridge, Massachusetts - CAPQ Colloquium, "Laser Spectroscopy of Stored Ions", February 4, 1981.

G. Materlik, Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany - CAPQ Colloquium, "Recent Developments in Synchrotron Radiation Research at DESY Hamburg", July 13, 1981.

J. Helmke, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany - CAPQ Colloquium, "Iodine Stabilized He-Ne Laser at 613 nm", July 16, 1981.

M. Ducloy, Universite Paris-Nord, Laboratoire de Physique des Lasers, Villetaneuse, France - CAPQ Colloquium, "Two-Photon Heterodyne Spectroscopy", July 28, 1981.

P. Siddons, Wheatstone Laboratory, Kings' College, Strand, London - CAPQ Colloquium, "Measurements of Anomalous Dispersion Using X-ray Interferometers", August 5, 1981.

## COMMITTEE MEMBERSHIPS

### Quantum Metrology Group - 520.06

R. D. Deslattes, Co-Chairman, International Conference on X-ray Physics, to be held in Eugene, Oregon, August 1982.

R. D. Deslattes, Member, Brookhaven National Synchrotron Light Source Users Advisory Committee.

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TECHNICAL ACTIVITIES

ELECTRICAL MEASUREMENTS AND STANDARDS DIVISION, 521

FISCAL YEAR 1981

## 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 magnitude and at the highest possible levels of accuracy. Its primary mission is to provide the central basis for a reliable and consistent system of electrical measurement throughout the U.S., including the Nation's scientific community as well as industry and commerce; and to ensure that the U.S. system is consistent with those of other countries.

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; electrical power revenue metering, transmission, and distribution; industrial process control; quality control in the manufacture of electronic components and products; testing and maintenance of electronic systems, which includes the civilian side of defense and aerospace; and national defense requirements directly under the Department of Defense. End user groups include scientists in universities; electric power utilities, both public and private; electric equipment manufacturers; process engineers who design, build, and use industrial process control systems; manufacturers of electronic components and consumer products; high technology civilian companies and government agencies involved with communications, computers, aerospace, transportation, health, and defense; and finally the armed services.

It is probably not an overstatement to say that the Nation's electric power system, the cost-effective manufacture of reliable consumer goods, the economic production of industrial materials, and a viable national defense would not be possible without adequate electrical measurements. And that the basis for all such measurements within the U.S. is the fundamental electrical units the 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, and 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 was made in the new experiment initiated in FY 80 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 electrical unit maintenance and dissemination, the needs of the EMSD's calibration clients were generally met; over 1000 calibration reports were issued with no significant errors. The professional staff situation was significantly improved with the addition of J. R. Hastings and the reprogramming of W. G. Eicke and J. E. Sims. Significant progress was made in improving the fabrication of Josephson junctions for voltage standard applications, in completing the all-cryogenic Josephson voltage standard, and in automating resistance calibrations ($10^7$ - $10^{13}$ ohms). A number of guest workers and coop and summer students contributed to the work in this area.

In the area of new measurement methods, good progress was made on an automated capacitance bridge covering the range up to 1000 pF and which should eventually find its way into the EMSD's capacitance calibration service. Significant improvements in the eddy current conductivity bridge which will be used to calibrate eddy current conductivity standards were also achieved.

In the area of precision measurement and fundamental constants, good progress was made in constructing the apparatus required to carry out the new $\gamma_p/\alpha$ determination. Significant progress was made in carrying out a new experiment to determine $\alpha$ and (simultaneously) to develop a new absolute resistance reference standard based on the quantized Hall resistance in two dimensional electron gases as realized, for example, in Si MOSFETs and GaAs-AlGaAs heterojunctions. Measurement accuracies of 0.2 ppm have been reached in less than a year. The Second International Conference on Precision Measurement and Fundamental Constants was held as planned 8-12 June 1981 and was deemed highly successful by all who attended (40% of the nearly 260 participants were from abroad). The Precision Measurement Grant Program also had a successful year -- with the help of additional funds from the NBS Director and NSF, four new $30K Grants were awarded.

In the area of international comparisons, the first in a series of comparisons of one-ohm resistance standards was initiated with CSIRO, Australia. The ultimate purpose is to test each laboratory's realization of the SI ohm via the calculable capacitor. Resistance comparisons were also carried out with PTB, West Germany and NRC, Canada, and a comparison of 10 pF capacitance standards with PTB was completed.

In the area of standardization, EMSD staff members continued to carry out their many committee responsibilities. The EMSD hosted the CODATA Fundamental Constants Task Group meeting in June 1981 and good progress was made on the 1981 least-squares adjustment of the constants.

In the area of training and education, higher priority staff commitments prevented the EMSD from conducting its DC-LF Seminar. Also, the pressure on the staff to complete projects already underway and maintain existing calibration services was such that no major tutorial material could be generated. (This situation will be alleviated to some extent in FY 82 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 and coop and summer students were successfully trained during the FY.

In summary, the EMSD has once again met its principal calibration responsibilities and made meaningful progress in a number of research areas. It was a successful year, all things considered.

## REALIZATION OF THE SI AMPERE
(P. T. Olsen, W. D. Phillips, E. R. Williams)

### Objectives

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 every been previously achieved. Determination of the SI ampere is periodically undertaken by NBS. This responsibility was given to 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) since the turn of the century. Continuing improvements in the measurements of other fundamental constants have permitted calculations which indicate that there are possible errors in the present ampere determinations or in the measurements of these other 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. Such an improvement would help to resolve the present discrepancies in the fundamental constants, as well as provide a means for monitoring the kilogram; and there is even the possibility that the new technique could lead to an artifact-independent definition of the kilogram and the mole.

### Current Activities

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

### Accomplishments

During FY 81 we have continued our preliminary ampere measurements using the Pellat, rotating coil balance. We have improved the mechanical stability, field strength, optics, current sources, weighing, and electrical metrology to the point where the day to day random scatter (or "noise") in ampere measurements is about 1 ppm. This is especially encouraging, since the relative contribution of both the weighing and voltage "noise" will be reduced by a factor of 100 in the final, superconducting version of the experiment.

We are aware of a relatively large (10-20 ppm) systematic error in our Pellat ampere determination, which we have not yet fully evaluated. It appears that we will only be able to evaluate this error, due to distortion of the balance beam, to 1-2 ppm. Even so, this would still represent the best direct measurement of the ampere ever made. Furthermore, this error is absent in the superconducting version of the experiment. From our experience with the Pellat balance, we have every reson to expect the final version of the experiment to yield an accuracy a few parts in $10^7$ or better.

## Future Plans

We will continue to study the systematic effects which now limit the Pellat determination of the ampere. If we can evaluate these well enough, we will have an ampere measurement with an uncertainty of a few ppm or less - better than any previous direct determination. Because of delays in construction by the outside contractor, we now expect to receive the superconducting coils early in calender year 1982. In preparation for this, we are building a non-superconducting prototype of the coils. This prototype will have noise characteristics similar to the Pellat balance, but without many of the latter's systematic errors. The protype will allow us to develop and test the weighing apparatus and moveable coil for the superconducting experiment before it is delivered and will let us test the operation of the experiment without the expense of liquid helium operation. The prototype should also provide us with an excellent measurement of the ampere before the installation of the superconducting coils. Most of the data acquisition and servo control systems developed for use with the Pellat balance will be directly applicable to the prototype and to the final superconducting version of the experiment. Thus, a preliminary result accurate to 1 - 2 ppm is expected by the end of FY 82 using either the Pellat configuration, the prototype coils, or superconducting coils.

# REALIZATION OF THE SI FARAD AND OHM

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

## Objectives

The objectives of this project are to build, maintain, and operate equipment for calibrating the NBS standards of capacitance and resistance in terms of their SI definitions, 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; and from a measurement of the quantized Hall resistance in a two dimensional electron gas.

## 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. A few years ago the capacitors were subjected to an unfortunately large temperature change. The only lasting effect of this occurence appears to be an increased drift rate which is, however, sufficiently small and linear so as to permit international comparisons at the part in $10^8$ level. The capacitors continue to exhibit excellent stability while being shipped via commercial carrier. They are presently in Canada and scheduled for France and Italy before returning to NBS.

Mr. Ho Chaolai, a guest worker from the People's Republic of China, has been with the Division since April 1981 and is expected to spend a total of two years here. Because of Mr. Ho's expressed interest in computers, it was arranged for him to actively participate in the writing and testing of two computer programs needed for the absolute ohm determination. The experience gained should enable Mr. Ho to contribute significantly to the rewriting of our

Fortran programs in the enhanced basic language of our newly acquired desktop computer.

Essentially all of the lower accuracy calibrations (0.1 ppm or higher) required for the comparison of the NBS units of capacitance and resistance have been completed. Although a considerable amount of higher accuracy calibration work was also done, much of this effort has been nullified by equipment failures and the resulting time lapse. The short term stability of components at the parts in $10^9$ level necessitates that calibrations at this level be made both before and after a capacitance-resistance comparison, and in a relatively short period of time. All defective equipment has now been repaired or replaced, and new calibrations have begun.

## Future Plans

New absolute farad and ohm measurements are in progress and will probably occupy 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. Effort will be made to upgrade the existing apparatus so that measurements of this frequency are practical. Also planned for FY 82 is an international comparison with CSIRO, Australia, of one ohm resistance standards calibrated in terms of each laboratory's calculable capacitor. This comparison should provide a good test of the overall reliability of each laboratory's measurement chain.

## REALIZATION OF THE SI VOLT
(F. K. Harris, 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 as the latter (5 ppm or more). However, a direct volt determination should be free from some of the systematic errors of past ampere determinations. Furthermore, there is no conversion of electrical energy to heat, which may have affected dimensional results and balance operation in past ampere determinations. Thus it is hoped that a direct determination of the volt may reduce the uncertainty in its assigned value.

### Current Activities

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

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

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

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

### Accomplishments

After assembly of the electrode structure of our electrometer, having regard for the constraints on symmetry and vertical alignment, evaluation of $\partial C/\partial z$ (see force equation) showed unacceptably large variations over the operating span of the carriage. Lateral motions of the balance base plate amounting to a few micrometers and correlated with the position of the carriage elevating screw and its drive train have been found. Thus, although the carriage orientation (horizontal alignment) has been decoupled from the elevating screw, the support structure has not been completely decoupled. Lateral displacement of the balance base plate must produce axial misalignment of the suspended electrode and thus contribute to variations in $\partial C/\partial z$.

## Future Plans

The carriage support structure is being modified in an attempt to improve its stiffness; and the elevating screw is to be replaced with a hydraulic system. If these changes result in a sufficient improvement in the behavior of $\partial C/\partial z$, we shall proceed with force measurements at the 1-gram level, where we should have about 1 ppm resolution.

## 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 interralated 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 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 objectives 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 appplications.

### Current Activities

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. Evaluation of the all-cryogenic voltage standard is underway, with present efforts directed toward resolving a significant systematic error between this system and the room-temperature voltage standard. 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 niobium-based junctions is nearing completion. Thin-film Josephson devices fabricated from the low-$T_c$ intermetallic compounds $AuAl_2$ and $AuIn_2$ are being studied, and an investigation of microwave enhancement of superconductivity of Al films is continuing.

### Accomplishments

In FY 81, there were eight comparisons of the Josephson voltage standard against NBS reference groups of saturated standard cells. The results of these measurements indicate the primary reference group NBS-13 is drifting at the rate of -0.15 ppm/month. Major improvements in the all-cryogenic voltage standard include the upgrading of the constant-current source. construction of a microwave generation system, modification of the switching arrangement and the use of a thermal superconducting switch for the preliminary junction voltage balances. Josephson voltage comparisons to standard cells using this system have started.

Niobium/Nb oxide/Pb Josephson devices for the commercial voltage standards have been produced in both thin-film deposition systems using different oxidation techniques (glow discharge and sputter-oxidation). Thin-film Josephson junctions of $AuAl_2$/oxide/Al and Al/oxide/$AuIn_2$ have been used to measure the temperature dependence of the energy gaps of these intermetallic compounds, and an all-low-$T_c$ material tunnel junction ($AuAl_2$/oxide/$AuIn_2$) has been fabricated for study. Investigations of microwave enhancement of superconductivity in Al using the double resonator configuration of the commercial and all-cryogenic voltage standards has yielded additional results that will be discussed at the 16th International Conference on Low-Temperature Physics. Results of the $AuAl_2$ and $AuIn_2$ work will also be presented.

## Future Plans

Comparisons of the Josephson voltage standard against NBS standard-cell reference groups will continue. The testing of Nb-based junctions will continue until a suitable device is found for the all-cryogenic Josephson voltage standard. Then a thorough investigation of possible sources of systematic error will continue in order to resolve the discrepancies between this system and the room-temperature voltage standard. The commercial Josephson voltage standards will be delivered in turn as they are brought into specification. 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 Riedell singularity.

Nb-based SRM Josephson devices will be produced for distribution through the Office of Standard Reference Materials. Using stripline techniques and Al tunnel junctions with sharp gaps, we will be able to investigate predictions (e.g., mixing with gain) of a recent quantum generalization of microwave-mixer theory as well as new predictions in the theory of non-equilibrium superconductivity (e.g., the role of the distribution function in photon-assisted tunneling). Finally, if time permits, a study will be initiated of zero current Josephson junction arrays for possible use as a "high voltage (i.e., $\sim$1 V) Josephson standard.

QUANTIZED HALL RESISTANCE
(M. E. Cage, R. F. Dziuba. B. F. Field)

Objectives

The ultimate project goals are to determine the fine-structure constant, $\alpha$, to the unprecedented accuracy of a few parts in $10^8$, and to establish an absolute, highly reproducible resistance standard of the same accuracy based on fundamental constants of nature.

The method for achieving these goals involves measurements of the Hall resistance, $R_H$, of metal-oxide-semiconductor field-effect transistors (MOSFET's) and of GaAs-$Al_xGa_{1-x}As$ heterojunctions at temperatures less than or equal to 4.2 K in large magnetic fields.

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 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 $I_{SD}$) is given by

$$R_H = \frac{V_H}{I_{SD}} = \frac{\mu_0 c}{2\alpha i} \approx \frac{25,813}{i}\ \Omega, \qquad (1)$$

where $\mu_0$ is the permeability of vacuum (exactly equal to $4\pi \times 10^{-7}$ H/m), c is the speed of light in vacuum, $\alpha$ is the fine-structure constant and i is an integer.

Current Activities

We are continuing the collaboration with R. J. Wagner of the Naval Research Laboratory (NRL) in studies of MOSFET devices using the 15 T superconducting magnet at the NRL high Magnetic Field Facility. The experiments on GaAs heterojunctions, being done with D. C. Tsui and A. C. Gossard of Bell Labs, have been so successful that Bell Labs is loaning us a 9 T superconducting magnet system, and we are preparing an experimental area for it.

## Accomplishments

A sensitive measurement system was developed, in which the Hall resistance is compared to a nominally-equal room temperature reference resistor via a potentiometer adjusted to within a few ppm of the Hall voltage. This system is 100 times more sensitive than the digital voltmeter method used by v. Klitzing, 10 times more sensitive than the Japanese potentiometric method, and twice as sensitive as the complex cryogenic current comparator systems being constructed in West Germany and England. The Si MOSFET experiments at NRL have yielded Hall steps flat to within at least 1 ppm at 1.5 K and 13 T, and the increased sensitivity revealed new features near the edges of the Hall steps. Most of our efforts were directed towards these new features (which we suspect are due to inhomogenities across the samples).

We have determined the value of $\alpha$ to within ±0.16 ppm using GaAs-$Al_xGa_{1-x}As$ heterojunctions. This uncertaingy is comparable to the ±0.11 ppm NBS $\alpha$ determination by E. R. Williams and P. T. Olsen from the gyromagnetic ratio of the proton, and the ±0.095 ppm QED theory-dependent value from the anomalous moment of the electron. Our result, $\alpha^{-1}$= 137.035968 ±0.16 ppm, is in excellent agreement with these two experiments. It is the first precision measurement for GaAs heterojunctions, and the uncertainty is 5.5 times smaller than the best previous quantized Hall resistance measurements.

## Future Plans

The appearance of features on the sides of Hall steps has led to a host of questions, some of which we hope can be answered by using a newly designed mask set which includes a selection of Si MOSFET samples with different lengths, widths and length/width ratios -- as well as a variety of Hall probe configurations. We will begin a program at NRL to investigate these questions, and will determine $\alpha$ to the same level of accuracy that we have just achieved for GaAs heterojunctions. We will also collaborate with P. J. Stiles of Brown University in studies of Si MOSFETs cooled to mK temperatures with a dilution refrigerator. These experiments will be done on superconducting magnets at the National Magnet Laboratory. Our major effort will be directed towards GaAs-$Al_xGa_{1-x}As$ heterojunction measurements at NBS. We will use two measurement systems: a modified version of the present system for studying the Hall step shapes, and a new automated system for precision measurements, including a more stable set of reference resistors. With this system we will be able to make comprehensive investigations of the flatness of Hall steps, carry out controlled high precision measurements of the Hall resistance, and test the device independence of the Hall resistance to the parts in $10^8$ level of accuracy.

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 instrumentation and physical standards necessary to carry out and 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 providing measurement services and persons engaged in exploratory research or in the measurement of fundamental constants. Those 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 last year. This year six of the automatic resistance bridges were constructed in the Temperature and Pressure Measurements and Standards Division (TPMSD, 522). Most of the further development of the automatic resistance bridge (e.g.,development of a 100 $\Omega$ version) was carried out in TPMSD and will be described in that division's section of the Annual Report.

This is the first year of a three year program to develop an automatic capacitance bridge. Most of the logic circuits have been completed, and designs have been produced for the transformer and the internal conductance standard. The internal capacitance standard was scheduled for completion by the end of the second year, but much of the development work for it has already been completed, including the construction of a simple and compact temperature enclosure that maintains temperatures to 100 microkelvin or so for respectable lengths of time. The electronic portion of the regulator is the subject of a paper co-authored by R. Davis of the Length and Mass Measurements and Standards Division that is to be published in the Review of Scientific Instruments this fall. The capacitance standard itself, although well along, will not be in a publication stage until at least a year of stability data has been obtained.

Future Plans

Development of the automatic capacitance bridge will continue.

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

## Objectives

The eddy-current project has two principal objectives: the development of a calibration service for electrical conductivity standards in the range 10%-100% IACS (international annealed copper standard); and the production of electrical conductivity standards which will become NBS Standard Reference Materials.

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

## 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.

The dc measurement system is being improved to increase the sensitivity of the measurements and the signal to noise ratio to the nanovolt level. This is being done through filters and impedance matching in various parts of the circuit. Calibration of the primary standards using various separations of the potential contacts is being done do determine more accurately the slope of the line for resistance vs. potential contact separation.

The eddy current bridge is continually being improved. The goal of this work is improved accuracy and simplicity of operation. Differences in measured values of coils of different geometry are being resolved. These differences appear to be caused primarily by coil temperature coefficients. The computer algorithm used to correct measured values for sensing coil-to-metal separation is being refined and tested.

The logistics of the electrical conductivity calibration service are being established. It is expected that the initial demands for this service will be quite high. Computer programs which calculate the inductance and resistance of a coil on metal are still being developed. The present effort is two-fold. First the calculation of the parameters for metals with varying conductivity and secondly for calculating performance of coils which contain separate driving and sensing coils in different configurations.

## Accomplishments

The following was accomplished during FY 81: (1) The new eddy current bridge has been completed and tested. A method of balancing ground circuits simultaneously with the main circuit was completed and tested. The accuracy and precision of the bridge have also been improved. (2) Two metal bars have been calibrated dimensionally and electrically and the resistivity of the bars have been determined. (3) The temperature coefficients for the two primary standards have been determined. (4) Some of the SRM's in the range 30% - 60% IACS have received final calibration. (5) Temperature coefficients for all test coils have been determined. (6) A computer algorithm has been written which corrects measurement reading for varying amounts of coil-to-metal separation and variations in temperature of the coil. (7) The book "Eddy Current Characterization of Materials and Structures" an ASTM STP has been published and distributed to attendees of the conference. (8) The third draft of a proposed ASTM Standard on measuring electrical conductivity by eddy current methods has been written. (9) The defect characterization system has been set aside for the moment due to problems in making matched sensing coils. Consultations with experts within and outside the Division have been held on the anomalies in test results. No solution to the problem has been found.

## Future Plans

Plans for FY 82 include the following: (1) Completion of the calibration of the current set of SRM's (30% - 60% IACS). (2) Formal announcement of the calibration service for electrical conductivity standards. (3) Manufacture and testing of two new primary standards of high resistivity, that is, in the range 10% - 30% IACS. These will serve as a check on Eddy current transfer techniques and possibly lower the uncertainty in the dc measurement. (4) Several new coil geometries will be tested. Their purpose will be to improve lift-off discrimination and reduce effects due to variations in coil temperature. (5) The feasibility of several new approaches for determining electrical conductivity using eddy currents will be tested. (6) A joint project with Division 564 will be directed at producing SRM's in the range 60% - 100% IACS.

## 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

Two distinct tasks are being carried out in collaboration with the staff of the Chemical Stability and Corrosion Division (CSCD, 561). Task A involves the development of a Fourier analysis program by the EMSD to process data resulting from the superposition of alternating current on an applied direct current as a means of improving corrosion measurements of specimens in the laboratory. Task B is directed to automating the measurements of corrosion rates of buried cables.

### Accomplishments

*Task A*. The completed computer software package performs harmonic (Fourier) analysis and is essentially machine independent. The package is comprised of three BASIC subroutines - PERIOD, DFT, and FFT. The 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. An error function is used to vary the estimate until the 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 input and search portions of the program are written 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 from this program, usually several hours of execution time per data set is required. Another program (FFT) employs fast Fourier transform methods to reduce the number of computations such that only several minutes are required to run a data set. Analysis of the results from running the FFT program using simulated data sets indicate this method has an accuracy of 0.15%.

An NBSIR is currently being written to document this effort. It is anticipated that this report will be completed in early FY 82.

Reconfiguration of the operating system and rewiring of some of the hardware appear to have corrected most of the serious problems encountered with the 7/32 computer used in the Volt Facility. Delivery of a new operating system and new hardware resulted in an inordinate amount of time being spent in changing the system, altering some of the old software, and writing new software.

Task B. Efforts begun in FY 80 to automate the NBS underground corrosion test site using the HP 9830 as the controlling computer continued. Because of the variety of instruments required for this project, it was necessary to design a controller to serve as the interface between the various instruments and the 9830's 8 bit parallel interface. Several possible methods were considered and the most attractive, from the stand point of both hardware and programming, required that the controller put out 12 bits to the various instrument control cards. The 12 bits were divided into a 4 bit address and 8 bits of data. This approach leads to simple programming; only two bytes are required to "talk" to the instruments. Reading is accomplished by simply addressing the instrument to be interrogated. Although not particularly efficient, it is the best technique of those studied. In principle the design of a controller to do the above is very simple. Several versions were designed and constructed early in the FY and none worked. Because of a lack of auxilary equipment such as a logic analyzer, progress was very slow. After several months of effort we found problems with the HP 9830 and the interface card that insured that our original designs were all doomed to failure. Because of these problems, it was not until well into the second quarter and the acquisition of a logic analyzer that we were able to get an interface design to work more or less properly, and it was not until July that all bugs were removed.

We reviewed with CSCD their needs for monitoring the various reference electrodes at the site and decided that it would be desireable to develop a scanner to permit the random selection of any two electrodes similar to the random access switch we designed and constructed last FY. Because of the possible use of such a scanner in a microprocessor based system in CSD, we decided to look at solid state devices. A prototype board with 16 random access

SPST channels was designed and constructed. In addition, a control board that allows expansion to 120 lines was also built. Preliminary tests indicate unresolved emfs (probably thermal) of less than 10 microvolts which is more than adequate for these measurements. Some data indicate that with the proper selection of the FET switches, it may be possible to reduce this figure to less than one microvolt.

In addition to the switch cards, cards have been designed and constructed for the DVM and programmable current source. By the end of FY 81, we should have the system at the field side for testing and evaluation.

Work has also continued on methods for resistance compensation. Several possible designs were evaluated and a method using two operational amplifiers and one multiplying DAC looks very promising. A prototype that is 9830 compatible will be constructed and evaluated in the next month or so. It is expected that all hardware will be in place by the end of FY 81.

## Future Plans

This work was terminated during FY 81. Mrs. Sims was assigned new duties associated with the dissemination of the volt. Initially she will have operational responsibility for the Volt Transfer Program (a MAP activity) and as she gains experience and current problems with the existing program are solved, she will assume additional responsibilities in the area of volt dissemination (especially documentation).

Mr. Eicke has been reassigned to (1) complete the Volt Facility (a task suspended with his reprogramming to corrosion research two years ago); and (2) collaborate with other division personnel in improving existing electrical dissemination services. In FY 82 the major thrust will be directed to completing the Volt Facility. Specific tasks identified to date are (i) the design and construction of an automated comparator using the Interdata 7/16 and the IEEE 488 bus to control the various components; and (ii) development of software to control the process. The plan is to develop a single system with two independent or nearly independent measurement methods that will handle both VTP and regular calibrations.

Some effort will also be made in FY 82 to prepare documentation describing the VTP and the related regional voltage MAP.

# GAMMA-P AND THE FINE-STRUCTURE CONSTANT

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

## Objectives

To extend the precision with which quantum electrodynamics (QED), the Josephson effect, and the von Klitzing effect (quantized Hall Resistance) can be tested by carrying out an improved measurement of the proton gyromagnetic ratio in $H_2O$, $\gamma_p'$. This should yield a value of the fine structure constant, $\alpha$, that is accurate to 0.01 - 0.02 ppm.

The present approach to redeterminating $\alpha$ is based on improving the inductive method developed in our laboratory and used to carry out a 0.2 ppm experiment reported in 1979. The NPL in England and the VNIIM in the USSR have recently reported values of $\gamma_p'$ that are in complete disagreement with our 1979 result (10-15 standard deviations). The Chinese value obtained at NIM, Beijing, agrees with our value. We expect a new determination of $\gamma_p'$ will resolve this major discrepancy.

## Current Activities

The gyromagnetic ratio of the proton is defined as the ratio of the angular precession frequency $\omega_p$ of a proton in a magnetic field B to the magnitude of the field, $\gamma_p = \omega_p/B$. 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. 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 previous experiment. This new experiment will have the following improvements: (i) a reduced sensitivity to the diameter of the solenoid; (ii) improved axial symmetry of the inductive pick-up probe; (iii) an improved 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 determination.

The new von Klitzing effect provides additional incentive for completing the $\gamma_p'$ measurement in the near future. The quantized Hall resistance, the absolute ohm, 2e/h from the Josephson effect, and $\gamma_p'$ form an over determined set of constants which allows $\alpha$ to be calculated by three different paths. The consistency of these three paths tests a great deal of physics as well as the quality with which the electrical standards are being maintained.

## Accomplishments

The latest theoretical calculations of the sixth and eighth order corrections to the electron anomalous moment by Levine and Roskies and by Kinoshita and Lindquist have eliminated the discrepancy between QED theory and experiment. In other words, the NBS value of $\alpha$ using $\gamma_p$ is now in good agreement with QED (i.e., within 0.15 ppm). Also, the value of $\alpha$ determined by the von Klitzing effect shows excellent agreement with our $\alpha$ value (i.e., within 0.04 ppm).

The USSR and England have, however, published values of $\gamma_p$ that are in complete disagreement with ours. NPL is (7 ± 0.5) ppm lower than NBS, while VNIIM is (5 ± 0.6) ppm lower. The Chinese/NIM value is (1.0 ± 0.8) ppm higher. These large discrepancies are very disturbing and graphically demonstrate how careful one must be in making an accurate $\gamma_p$ measurement.

The new 2.5 m precision solenoid has been lapped with a helical grove and wound with copper wire. It should soon be rewound with gold plated copper wire and the tedious, time consuming, construction of the new solenoid will be completed. A 3 m straight edge has been polished and is straight to about $10^{-5}$ m, completing that tedious job. A new and very simple method to detect the leakage between turns of the solenoid has been demonstrated on the old one-meter solenoid. This technique will eliminate any significant uncertainty in $\gamma_p$ due to leakage.

## Future Plans

Assembly of the apparatus will occupy most of our time during FY 82. We have chosen to concentrate on this approach rather than the new Ampere's Law approach because we feel confident that an improved value can be obtained within two years.

The special solenoid for measuring the susceptibility of the precision 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 windings. 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.

With the recent advances in the theory of the electron anaalous moment and with the new quantized Hall resistance, the need for immediate new results for $\gamma_p$ has greatly increased. Now that the tedious construction phase of our experiment nears completion, we can respond to this added pressure by spending a larger percentage of our time on the $\gamma_p$ experiment itself.

## 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 possibly 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 benefited 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.

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.

### 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. The slow atoms could be trapped by another laser beam, or used as a cold atomic beam for high resolution spectroscopy. We are also considering confinement in static magnetic or electric fields.

### Accomplishments

During FY 81 we have observed for the first time clear effects of laser cooling of an atomic beam. The earliest indications were from some experiments where a rapidly scanned, circularly polarized laser was used in conjunction with an axial magnetic field to both cool and detect atoms. Since this arrangement leads to ambiguities, we developed a two laser system for separate cooling and detection processes. The velocity distribution is measured from Doppler shifts using a very weak probe beam which neither saturates nor optically pumps the atoms, while the cooling is accomplished with a strong fixed frequency laser which is turned off during the observation time. Using a differential technique, we have seen clearly the effects of optical pumping and of cooling. The cooling process produces a monochromotization of the velocity distribution as well as a shift to lower velocity, as has been predicted by theory.

We have seen that the cooling process improves consideraly as a stronger magnetic field (up to 250 gauss) is used to better define a quantization axis and to separate different quantum states so as to avoid the optical pumping which limits the number of times atoms can interact with the laser. We have constructed a solenoid that will provide fields in excess of 1000 gauss, and that better separates the cooling and detection regions. This should allow ofr more effective cooling and easier analysis of the results.

## Future Plans

During FY 82 we will be concentrating on optimizing the cooling effect. One way in which this will be done is with a stronger magnetic field, which varies spatially so as to keep the atoms on resonance with the fixed frequency laser. We will also consider a fast scanned cooling laser using the new time resolved analysis technique. Other schemes such as multiple lasers, or multi-frequency lasers are being planned to overcome some of the effects of optical pumping. We may make use of time-of-flight velocity analysis to further separate our experimental observation of optical pumping and cooling effects.

We will also attempt to fit our experimental results to a theoretical model which includes the effects of optical pumping as well as cooling. We may also use our new observation techniques to provide more insight into some unexplained long-time optical pumping effects seen in the early stages of this work. Our immediate objective will be to determine what experimental factors affect the efficiency and limits of the cooling and how they can be manipulated to maximize the cooling. We expect to be able to produce a beam of atoms of significantly reduced energy in the near future and eventually to apply this achievement to trapping, spectroscopy, and standards.

## FUNDAMENTAL CONSTANTS DATA CENTER
(B. N. Taylor)

### Objectives

The principal objectives of this project are to provide an international information center within the U.S. for work in the general area of precision measurement and fundamental constants, to analyze the consistency of measured values of the fundamental constants that are obtained from different 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 measurement 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 reporducible, 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" (PPMFC) for the OSRD (this publication lists preprints as well as reprints of PMFC papers); (5) attending and organizing national and international conferences on PMFC 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 cooparative agreement in metrology; and (8) answering numerous inquiries from both within and without NBS relating to the PMFC field.

## Accomplishments

The following was accomplished in FY 81: (i) published four quarterly issues of PPMFC; (ii) responded to numerous written and oral inquiries regarding the fundamental constants; (iii) attended the April meeting of the NAS/NRC Fundamental Constants Committee and contributed to the preparation of a report documenting the importance of the PMFC field to physics and the need for continued, strong support of the field; (iv) organized and held the Second International Conference on Precision Measurement and Fundamental Constants (PMFC-II), 8-12 June 1981. This was a highly successful meeting which brought together over 250 workers in the PMFC field from all over the world and laid the groundwork for the 1981 Least-Squares Adjustment of the Fundamental Constants (LSAFC); (v) began work on the 1981 LSAFC, in particular, developed the necessary computer programs required to analyze discrepant data and prepared a NBS-IR in which various algorithms for treating discrepant data are numerically compared; (vi) participated in the work of the CODATA Task Group on Fundamental Constants related to the 1981 LSAFC, in particular, attended a meeting in June 1981 during which the problems associated with the adjustment were discussed in detail (hosted the latter meeting); (vii) worked with Keith Eberhart, Center for Applied Mathematics, on a new method for analyzing the data relating to the determination of atomic weights using dilution mass spectrometry (applicable to the Faraday constant); and (viii) participated in NBS' Ad Hoc Committee on Uncertainties, in particular, helped Ronald Colle prepare the NBS position prior to the BIPM Uncertainty Committee meeting in October, 1980.

## Future Plans

The following is planned for FY 82: (i) publish as usual the quarterly PPMFC; (ii) respond to inquiries as received; and (iii) attend the April 1982 meeting of the NAS/NRC Fundamental Constants Committee. The main objectives in FY 82 will be (iv) to complete the 1981 least-squares adjustment of the constants, to oversee its adoption for international use by CODATA, and to prepare several brief reports summarizing the adjustment for NBS, CODATA, and other organizations; and (v) to complete the editing of the proceedings of the Second International Conference on Precision Measurement and Fundamental Constants and oversee its publication (the target publication date is late FY 82).

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

### Objectives

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

The importance of research in the precision measurement-fundamental constants field has been covered in the project report entitled FUNDAMENTAL CONSTANTS DATA CENTER. While NBS has a strong interest in this area and much experimental work underway, it cannot do it all - there is much expertise and relevant work in the colleges and universities. It is the purpose of this project to tap this reservoir 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

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

## Accomplishments

A request was sent to and was approved by the NBS Director to increase each new PMG from $25 K to $30 K to partially compensate for inflation (the $25 K level had been in effect since 1977). A proposal to NSF requesting their participation in the NBS PMG program was approved and NSF gave NBS sufficient funds to award two additional new grants. The procedures outlined above for selecting candidates, which were first instituted in FY 77, were again used successfully in FY 81. 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 30 candidates, five of whom were chosen to submit final, full proposals. The four grantees selected from these five were:

David F. Bartlett, University of Colorado;
Proposal Title: Eotvos Experiment -- a Cryogenic Version

David A. Church, Texas A & M University;
Proposal Title: Low Energy, Highly Charged Ion Precision Spectroscopy

Charles E. Johnson, North Carolina State University;
Proposal Title: RF Spectroscopy of Atomic and Molecular Ions

Michael G. Littman, Princeton University;
Proposal Title: Fine-Structure Constant Determination Using Precision Stark Spectroscopy

For FY 81, the NBS Precision Measurement Grants Committee consisted of Drs. Deslattes, Hall, Taylor and Wineland; the Outside Advisory Committee of Professors Kleppner, Pipkin, Robinson, and Schuessler.

The following four $25K Grants were also renewed during FY 81: W. H. Wing, U. Ariz., Electrostatic Trapping of Neutral Atomic Particles; W. C. Oelfke, U. Central Florida, Quantum Limited Measurement of a Harmonic Oscillator; C. E. Wieman, U. Mich., Measurement of Fundamental Constants Using Three-Level Resonances in Hydrogen; and W. C. Sauder, Virginia Military Institute, Precise Determination of the Gas Constant: First Applications of the Ultrasonic Michelson Interferometer.

Fifteen of the 30 past or present PMG recipients attended the June 8-12, 1981 Second International Conference on Precision Measurement and Fundamental Constants at NBS, and 13 of these presented papers. The most significant accomplishment under PMG sponsorship this FY was undoubtedly the measurement of the proton to electron mass ratio by R. S. Van Dyck, U. Washington [P.R.L. 47, 395 (1981)] using a Penning trap.

## Plans

FY 82 plans naturally focus on renewing the 6 current grants and awarding four new grants. It should be noted, however, that NSF support is not automatic -- it is NSF policy not to give regranting authority. This means that NSF retains the right to approve the two Grants for which they supply the funds; if they are not satisfied the work proposed and the P.I. is NSF quality, they will decline to support the project. However, no distinction is made between the PMG's supported by NBS funds and those supported by NSF funds -- to the PMG recipient, it is an NBS Precision Measurement Grant (there is absolutely no contact between the recipient and NSF).

DISSEMINATION SERVICES: SUPPORT AND OPERATION INCLUDING MAP DEVELOPMENT
(N. B. Belecki, C. R. Childers. R. F. Dziuba. R. C. Fronk, J. Hastings, C. R. Levy, R. E. Long, T. P. Moore. D. D. Prather. J. Sims, A. R. Wise)

## Objectives

The overall objective of this project is to enable all measurements of electrical quantities performed in the United States to be made in terms of the U.S. legal electrical units at the 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 availablity 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-service support activities are STRS-funded projects directed toward continuing the viable operation of the measurement services above, developing improved quality control procedures for them, making both evolutionary and revolutionary improvements in technique and equipment, and increasing their efficiency to ensure that the services offered are sufficient in type and accuracy to fulfill the most stringent requirements for measurements support

from industry, government, and the scientific community. The bulk of the effort is going toward automation and MAP development.

The professional manpower situation has been considerably improved by the addition of John Hastings to the staff in December, 1980, and the reprogramming of Eicke and Sims from corrosion work back into this program. Hastings, who came from the Thermophysics Division, has been in training to assume responsibility for the ac-dc difference area. He has already proven to be of significant help in reviewing calibration reports and, as his grasp of the field improves, is expected to contribute significantly in the areas of improved quality-control procedures, documentation, advanced standards, and MAP development.

Sims, whose background is that of computer science and electrical engineering, has had some experience in precision voltage measurements and considerable experience in the area of data reduction. She has been given responsibility for operations in the Volt Facility and for the voltage MAP. She has already made inroads into the MAP backlog and has been working on bringing the transport standards up to an acceptable level. It is anticipated that with her efforts, the voltage MAP will be a much more viable and timely service starting in FY 82.

Eicke, a senior professional with an international reputation in the area of standard cell metrology and MAP applications, will be responsibile for completely automating the Volt Facility and for setting up proper operating procedures for both the regular voltage calibration services and the MAP services. He has worked out an improved approach for the automation and much of the hardware needed for its implementation has been ordered. His work should go a long way towards relieving the manpower shortage in this technical area by significantly reducing the 0.7 MY/year effort now required to calibrate customer voltage standards manually.

A great deal of support was also obtained in FY 81 from three co-op students, all working under the supervision of R. Dziuba. K. Baker spent two semesters working in the resistance area where he made major contributions to our automation effort and made precision resistance intercomparisons which enabled us to continue to offer MAP services at a high level of quality. P. Boynton spent the summer working in the high-resistance laboratory, where he performed the hardware modifications and wrote the software necessary to automate the digital teraohm meter. This can now be used to calibrate resistance standards in the range $10^7$ to $10^{13}$ ohms, freeing some technician time.

Finally, J. Glenn spent the summer evaluating Josephson junctions designed for use in the all-cryogenic Josephson apparatus and making measurements on solid-state voltage standards, thus reducing the burden of five senior people in these areas.

## Accomplishments

1. A Technical Note describing in detail the calibration and use of thermal transfer converters has been written under contract by E. S. Williams and will be published in the next few months. (Belecki, Hastings)

2. A pilot experiment with the intent of establishing do-it-yourself MAP's in the resistance area has been started with six southern California companies - Autonetics, Beckman, ESRS, Ford Aerospace, Lockheed California, and TRW Space Systems. (Dziuba, Belecki)

3. Voltage MAP data were analyzed to determine criteria for deletion of bad data and to establish long-term behavior statistics for transport standards. This resulted in rebuilding several standards [Sims, Belecki, Kefadar, Reeves (Div. 714)]

4. A photocell amplifier has been modified to permit the use of a digital voltmeter to balance the ampere-turn potentiometer for one-ohm resistor intercomparisons. The system has been tested and found to work satisfactorily. (Dziuba, Baker)

5. A microprocessor system has been implemented in the resistance laboratory to facilitate data collection from the one-ohm resistance calibration facility. (Dziuba, Baker)

6. An automated system for the measurement of high-valued resistors. based on the use of a commercial teraohm meter as a transfer device between NBS standards and unknown resistors, has been implemented and tested. (Dziuba, Boynton, Childers)

7. By the end of August, the group had calibrated 1050 electrical standards, with no technical errors reported and generally on time. A detailed breakdown of this activity is given in the Summary of Calibration Activities. (Baker, Childers, Fronk, Levy, Long, Moore, Prather, Wise)

## Future Plans

In addition to continuing the the Division's SP 250 calibration services at a high quality level, our objectives for FY 82 include:

1. The generation of a detailed set of instructions for the Volt Transfer Program, our voltage MAP.

2. The construction and testing of a prototype system for automatically measuring standard cells, and

3. The completion of a study on the primary standards for ac current and voltage measurements. This includes assessing their accuracies and detailing the uncertainties in the calibration process for thermal transfer standards.

## IMPROVED STANDARDS FOR WIDE RANGING ENVIRONMENTS
(B. F. Field)

### Objectives

The overall objective of this project is to develop new electrical standards with state-of-the-art performance for use outside the standards laboratory environment.

Voltage and resistance references presently available for use as secondary standards (i.e., for use in a production-line environment) are from 10 to 100 times less accurate than their standards laboratory equivalents (so-called "primary standards"). This project will identify problems with existing secondary standards and attempt to develop improved voltage and resistance standards with accuracies comparable to "delicate" primary standards.

For voltage standards, where the need is greatest, we will develop measurement systems to characterize reference devices, establish liaison with appropriate industrial companies, characterize presently-available reference devices, and explore the physical phenomena underlying solid state references. In addition we will investigate semiconductor processing parameters that affect long term device stability, with the eventual goal of developing an improved solid-state standard with stability performance comparable to a standard cell.

To minimize the effect of transportation on resistance standards, we will design improved and ruggized wirewound standards, and explore modern circuit technology as a potential source of new standards. This will include investigating the use of cryoresistors as new primary standards.

### Current Activities

We are proceeding in the construction of an IEEE 488-based system for fully automatic measurement of any voltage in the range 1 to 10 volts, with an initial design accuracy of 0.2 ppm. The instrument consists of a resistance network of 10 series connected 1000 $\Omega$ resistors fed by a constant current source. This arrangement produces 10 volts across the resistor string with ten taps at one volt increments. The unit under test is compared to a voltage produced by the 10 V tapped source that most nearly equals the voltage of the unit under test. The difference voltage is read by a high accuracy digital voltmeter. A low thermal-emf cross bar switch is used to connect up to 80 devices to the measuring circuit.

High measurement accuracy (0.2 ppm) is expected as a result of a careful evaluation of all the system components and a measurement design technique that compensates for systematic errors in the measuring system. The desktop computer which controls the measuring system is programmed to evaluate and correct the data for all the major sources of error of the digital voltmeter, including offset, gain, and nonlinearity errors.

We have been in contact with several of the leading voltage reference device manufacturers such as National Semiconductor and Standard Reference Labs, as well as instrument manufacturers such as John Fluke Mfg. Co. We are presently exchanging information and evaluating some prototype and production standards submitted by various manufacturers. Full scale testing of devices will begin when the automated measuring system is completed.

## Accomplishments

While the automated system described above is under construction, a manual measurement system (designed and constructed by N. B. Belecki) is being employed to do limited testing of some voltage standards. This system, accurate to approximately 0.3 ppm, has been used to evaluate a 3 "cell" Zener reference that was transported and calibrated at four national laboratories. Agreement between the laboratories was within 2 ppm.

## Future Plans

The automated voltage measuring system will be completed and tested. Appropriate software is being written to measure up to 80 voltage references and analyze the measurement data. A 20 Mbyte disk with removeable cartridges has been installed on the desktop computer to provide storage for the large volume of data expected. The effect on voltage references of changing temperature and humidity conditions will be studied using a large environmental chamber located nearby. We also plan to build a system to analyze the noise spectrum of selected references. Transportation of standard cells requires special handling, whereas some voltage references may be moved with much less care. Therefore we will determine the transport standard capabilities of present references under field use conditions.

Improved resistance standards will be constructed possibly using a new CSIRO (National Measurement Laboratory, Australia) design. New packaging and mounting structures will be designed and incorporated into prototypes of new generation one ohm and 10 k ohm standards. We also eventually intend to investigate the use of cryoresistors as new primary standards.

## Conferences Sponsored

Second International Conference on Precision Measurement and Fundamental Constants, 8-12 June 1981. Over 250 individuals from around the world (40% from abroad) participated. The Conference provided an international forum for scientists engaged in experimental and theoretical research on precision measurements relating to the fundamental physical constants, and on the testing of related fundamental theory. It also laid the foundation for the 1981 least-squares adjustment of the fundamental constants.

## Invited Talks

M. E. Cage, "Determination of the Fine-Structure Constant and an Atomic Standard of Resistance Based on the Quantized Hall Effect", Baltimore Meeting of the American Physical Society, 20-23 April, 1981.

W. G. Eicke, "Ten Years of the Regional Measurement Assurance Program", Joint Meeting of the Greater Los Angeles Chapters of the Precision Measurement Association, Los Angeles, California, February, 1981.

E. R. Williams, "The Proton Gyromagnetic Ratio in $H_2O$ - A Problem in Dimensional Metrology", Second International Conference on Precision Measurement and Fundamental Constants, NBS Gaithersburg, 8-12 June, 1981.

Publications

1. In Print.

M. E. Cage, An Analysis of the Effects of Dynamic and Static Forces Present in the NBS SI Volt Experiment, NBSIR80-2143, September, 1980.

G. M. Free, High-Accuracy Conductivity Measurements in Nonferrous Metals, in Eddy-Current Characterization of Materials and Structures, ASTM Special Technical Publication 722, Ed. by G. Birnbaum and G. M. Free (American Society for Testing and Materials, 1981) p. 121.

G. M. Free, L. K. Ives, R. Mehrabian, and L. J. Swartzendruber, Nondestructive Evaluation of Nonuniformities in Aluminum Alloy Plate, in Proceedings of the American Society for Nondestructive Testing Fall Conference, 1980, p. 39.

O. P. Galakhova, S. Harkness, F. L. Hermach, H. Hirayama, P. Martin, T. H. Rozdestvenskaya, and E. S. Williams, An International Comparison of Thermal Converters as AC-DC Transfer Standards, IEEE Trans. Instrum. Meas. IM-29, 396 (1980).

L. B. Holdeman, James T. Hall, D. Van Vechten, and R. J. Soulen, Jr., Gap Enhancement in Aluminum Tunnel Junctions Coupled to Microstrip Resonators, Physica 108B, 827 (1981).

R. L. Kautz and G. Costabile, A Josephson Voltage Standard Using a Series Array of 100 Junctions, IEEE Trans. Mag. MAG-17, 780 (1981).

H. J. Metcalf and W. D. Phillips, Time Resolved Subnatural-Width Spectroscopy, Opt. Lett. 5, 540 (1980).

P. T. Olsen, M. E. Cage, W. D. Phillips, and E. R. Williams, The Realization of the Ampere at NBS, IEEE Trans. Instrum. Meas. IM-29, 234 (1980).

R. J. Soulen, Jr., D. Van Vechten, G. Costabile, Terrence Jach, and L. B. Holdeman, The Superconductive Energy Gap of $AuAl_2$, Physica 108B, 823 (1981).

E. S. Williams, A Thermoelement Comparator for Automatic AC-DC Difference Measurements, IEEE Trans. Instrum. Meas. IM-29, 405 (1980).

2. In press, in Review, or Nearing Completion.

M. E. Cage and R. S. Davis, An Analysis of Read-Out Perturbations Seen on an Analytical Balance with a Swinging Pan, NBS J. Research.

M. E. Cage, R. F. Dziuba, B. F. Field, C. F. Lavine, and R. J. Wagner, Status of the NBS-NRL Determination of the Fine-Structure Constant Using the Quantized Hall Resistance Effect, in Proceedings of the Second International

Conference on Precision Measurement and Fundamental Constants (hereafter reffered to as NBS Spec. Publ. 617).

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

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

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

B. N. Taylor, Numerical Comparisons of Several Algorithms for Treating Inconsistent Data in a Least-Squares Adjustment of the Fundamental Constants, NBS-IR.

B. N. Taylor and W. D. Phillips, Eds. of Precision Measurement and Fundamental Constants II, Nat. Bur. Stand. (U.S.) Spec. Publ. 617, in press (to appear late FY 82).

D. C. Tsui, A. C. Gossard, B. F. Field, M. E. Cage and R. F. Dziuba, A Preliminary Determination of the Fine-Structure Constant Using GaAs-$Al_x Ga_{1-x} As$ Heterostructures, Phys. Rev. Lett.

R. J. Wagner, C. F. Levine, M. E. Cage, R. F. Dziuba, and B. F. Field, Measurements of Quantized Hall Steps in Si at the PPM Level, Surface Science.

Technical and Professional Committee Participation and Leadership

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

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

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

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

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

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

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

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

G. M. Free, member, ASTM E7, American Society for testing and Materials, Nondestructive Testing: ASTM E7, SC.7, Electrical and Magnetic Methods (vice chairman); and E7,Sc.9, Materials Inspection and Testing Laboratories.

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

G. M. Free, Secretary, American Society for Nondestructive Testing, C1, 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, Chairman, NBS Precision Measurement Grants Committee.

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

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

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

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

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

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).

## 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 is also serving as a member of NBS' Calibration Advisory Group.

N. B. Belecki reviewed the proposed syllabus for a two-year metrology course at Butler County Community College in Pennsylvania under the auspices of NCSL.

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

M. E. Cage collaborated with 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 S. M. Girvin of the Surface Science Division (541) and R. W. Rendell of the Radiation Physics Division (533) on the theoretical aspects of the quantized Hall resistance experiment.

M. E. Cage, R. F. Dziuba, and B. F. Field collaborated with P. J. Stiles of Brown Univeristy, R. J. Wagner and C. F. Lavine of the Electronics Technology Division of the Naval Research Laboratory, and with the staff of the Research Device Facility of the Naval Research Laboratory, in the design and fabrication of a new mask set for Si MOSFETs.

M. E. Cage, R. F. Dziuba, and B. F. Field are collaborating with R. J. Wagner and C. F. Lavine of B. D. McCombe's Electronics Technology Division the Naval Research Laboratory, on quantized Hall resistance measurements using the 15 T NRL superconducting magnet and Si MOSFET devices.

M. E. Cage, R. F. Dziuba, and B. F. Field are collaborating with D. C. Tsui and A. C. Gossard, Bell Laboratories, on quantized Hall resistance measurements using a Bell Labs 10.5 T superconducting magnet and GaAs-$Al_xGa_{1-x}As$ heterojunctions.

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

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

R. F. Dziuba collaborated with K. Harmans, Van Swinden Laboratory, the Netherlands, on improving the performance on an NBS all-cryogenic Josephson voltage standard system.

R. F. Dziuba has collaborated in the training of George Gillies, newly hired as an electrical metrologist by the International Bureau of Weights and Measures (BIPM).

R. F. Dziuba and J. Q. Shields are collaborating with A. M. Thompson, CSIRO, Australia, on the comparison of the NBS and CSIRO realizations of the SI ohm via the calculable capacitor by measuring a new type of one-ohm, transportable resistance standard.

W. G. Eicke has provided consulting services to personnel in the Office of Energy-Realated 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 C. Waters, 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 alloys.

G. M. Free Collaborated with Caius Dodd of Oak Ridge National Laboratories on an experiment to determine the electrical conductivity of metals directly by eddy current methods.

G. M. Free Collaborated with Jeff Bailey of Kaiser Aluminum in a round-robin measurement of aluminum electrical conductivity standards. The information gathered will be used to evaluate the accuracy and precision with which members of the aluminum manufacturers association measure this quantity.

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

L. B. Holdeman is collaborating with R. J. Soulen, Jr., and D. VanVechten 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 D. VanVechten (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 the oxidation of $AuAl_2$.

L. B. Holdeman and J. Toots made numerous thin-film depositions as an informal service to various research groups within NBS: e.g., deposition of gold contacts onto carbon wafers for low-temperature thermometry (B. Dove, R. Soulen, H. Marshak, 522); fabricated large-area platinum-silicon Schottky-barrier diodes as prototype soft x-ray detectors for the NBS beam line at the Brookhaven National Synchrotron Light Source (T. Jach, 541); deposited a series of gold films onto suspended formvar films for calibrating the Mott scattering apparatus built by the Electron Physics Group to detect electron spin polarization (D. Pierce, S. Mielczarek, 533); and fabricated a thin-film platinum bolometer (K. C. Harvey, 520).

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. J. Metcalf, SUNY, Stony Brook, on the use of magnetic fields in the laser cooling of neutral atomic beams; and collaborated with Metcalf on the analysis of subnatural Doppler-width spectroscopy.

W. D. Phillips is collaborating with R. J. Santoro of the Thermal Processes Division (566) on the application of rapid laser frequency scanning to the study of transient systems.

J. Q. Shields is collaborating in the training of Ho Chaolai, an electrical metrologist from NIM, Beijing, PRC.

J. E. Sims collaborated with U. Bertocci of the Chemical Stability and Corrosion Division (561) on development of a Fourier analysis computer 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 late 1981 or early 1982 for international adoption by CODATA in 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 served as Chairman of the Conference Committee which organized the Second International Conference on Precision Measurement and Fundamental Constants held at NBS/Gaithersburg, 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.

B. N. Taylor and W. D. Phillips are editing the Proceedings of the Second International Conference on Precision Measurement and Fundamental Constants.

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-Gosstandard collaboration in metrology.

E. R. Williams is collaborating with G. L. Greene, Yale University, on testing Greene's new technique (Ramsey separated oscillatory field magnetic resonance) to determine the proton gyromagnetic ratio.

E. R. Williams is collaborating with G. T. Gillies, BIPM, on the development of a new approach to detecting free quarks.

## EMSD Calibration Summary for FY 81
(as of 8/31/81)

SP 250 - 3.1 Resistance Measurements
523 Standard resistors and shunts
3 MAP Transfers

3.2 Precision Apparatus
28 Inductive Voltage Dividers

3.3 Impedance Measurements
185 Standard Inductors
218 Standard Capacitors

3.4 Voltage Measurements
106 Standard Cell Enclosures
(402) Standard cells)
22 MAP transfers

3.5 Electrical Instruments (AC-DC)
53 Standard Thermal Converter Instruments
(773 points)

Estimated FY 81 Billing $375,000

MEASUREMENTS AND STANDARDS DIVISION

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ʾ 1981

ʾ into three major areas

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TEMPERATURE AND PRESSURE MEASUREMENTS AND STANDARDS DIVISION

SUMMARY OF ACTIVITIES

FISCAL YEAR 1981

## I. INTRODUCTION

The activities of the TPMSD can be divided into three major areas of responsibility. These are:

1. Providing access to the national scales of temperature and pressure for technical groups throughout the U.S.;

2. Developing new standards for the measurement of temperature and pressure which are more accurate or more useful; and

3. Performing scientific research which may lead to new types of high-precision temperature or pressure sensors or to a better understanding of temperature or pressure measurement.

During the past year, the TPMSD staff was active in each of these areas. In the following narrative, we note the names of staff members who have done the work under discussion. Often, a staff member contributed in all three areas; this situation is a natural consequence of the close connection between the calibration and research responsibilities of the Division. In some instances, substantial portions of the work were done by Guest Workers, Summer Academic staff, or visiting scientists; we have tried to acknowledge this assistance as well.

## II. CALIBRATION, INSTRUCTION, AND CONSULTATION

In setting the original charter for the NBS, Congress decreed that the Bureau should disseminate to U.S. science and industry the means of measurement of physical quantities. The TPMSD still regards this responsibility as providing for its most direct contribution to American productivity; the resulting activity is certainly the Bureau's most visible from the point of view of American industry.

The Division discharges its responsibility to provide access to standard measurements of temperature and pressure through three activities:

*Calibration of "standard" sensors for temperature and pressure;

*Formal instruction in the techniques of precision measurement of temperature and pressure; and

*Consultation on an individual basis with personnel from U. S. scientific or industrial organizations.

A. <u>Calibrations</u>

The NBS Special Publication 250 provides the basic information by which the majority of requests for calibration of temperature or pressure instruments reach NBS. It contains a listing of the procedures most frequently needed along with their prices, and it also refers to the availability of specialized calibration services available on an "at cost" basis. Here we summarize the fee-paid services performed during the past year:

*Laboratory thermometers (liquid-in-glass type) - J. A. Wise, calibrator. 661 liquid-in-glass thermometers, 25 thermocouples, and 24 platinum resistance, thermistor, digital or other temperature sensors calibrated for 166 customers representing major manufacturers of thermometers; U.S., state, and local governments; manufacturers of consumables and durable goods; utilities; and universities and hospitals.

*Thermomcouple thermometers - M. G. Scroger, calibrator. 300 thermometers calibrated for 95 customers representing major manufacturers of thermometers; U.S. government agencies; manufacturers of durable goods; utilities; and universities.

*Platinum resistance thermometers - W. R. Bigge, calibrator. 77 thermometers calibrated for 64 customers representing major thermometer manufacturers; U. S. government agencies; durable goods manufacturers; utilities; and universities.

*Germanium-based cryogenic thermometers - E. R. Pfeiffer, calibrator. 5 thermometers calibrated for NASA and thermometer manufacturers.

*Gas-operated piston gages - R. G. Driver, 26 multiple-range gages calibrated for major gage manufacturers, for utilities, industrial users, and U.S. government agencies;

*Oil-operated piston gages - W. Markus, calibrator. 20 multiple-range gages calibrated for manufacturers, utilities, NOAA, NASA, military and private industry.

*Mercury manometers - B. E. Welch, calibrator. 4 manometers calibrated for manufacturers, auto industry, and chemical industries.

*Low-range Ball gages - R. W. Hyland, calibrator. One calibrated for Ametek, Inc.

*Capacitance diaphragm manometers - R. W. Hyland, calibrator. 11 gages calibrated for a variety of government laboratories and private corporations.

*Ionization vacuum gages - K. E. McCulloh and C. R. Tilford, calibrators. 3 gages calibrated for NASA and U. S. government contractors. 6 gages calibrated under DoE sponsorship (not for fee) for LASL.

Besides the relatively frequent calibrations of the types noted above, the calibration staff provide many calibrations as participants in international comparisons of laboratory standards or of laboratory techniques. During the past year, an international piston gage interlaboratory comparison continued [4].

An additional calibration activity is known as a "Measurement Assurance Program" (MAP) calibration; in this case the intention of the activity is to ascertain the overall level of accuracy currently being achieved by a participating laboratory. The TPMSD MAP activity is directed by the NBS Office of Measurement Services. Two general areas are involved -- thermometry in the range covered by the new Provisional 0.5 K to 30 K Temperature Scale (EPT-76), and the PRT range (14 K to 904 K). Three major suppliers of cryogenic thermometers have requested that NBS provide a MAP in the EPT-76 range; therefore, the low-temperature MAP is addressed to their needs. E. R. Pfeiffer and R. S. Kaeser accomplished the following results:

*Comparison of thermometers incorporating the IPTS-68; the NBS 2-20 K Acoustic Scale; the NPL-1975 Gas Thermometry Scale; and the SRM 767 superconducting fixed point device from 0.5 K to 30 K;

*Calibration of 9 germanium thermometers over the same range;

*Completion of an automatic data acquisition and processing program known as "MOOSE"; and

*Development of interpolation relations for the germanium thermometers.

In the PRT range, the capabilities of two additional laboratories were evaluated with respect to calibration accuracy of standard IPTS PRT's [5]. In addition, work was continued through ASTM committee E-20 on an evaluation of the calibration capabilities of industrial thermometer manufacturers.

The calibration of ionization-type vacuum gages mentioned above is a new service of NBS, just instituted during the past year. The calibration of liquid manometers is discouraged because the accuracy of these instruments is quite sensitive to user procedures.

### B. Precision Measurement Seminars

The TPMSD offers two formal instructional seminars to the public on a fee-paid basis. One of these, the Precision Thermometry Seminar, consists of theoretical and laboratory instruction in the use of platinum resistance thermometers, liquid-in-glass thermometers, thermocouple thermometers, and thermistor thermometers. The instructions are given by the calibration staff and their supervisors. The Precision Thermometry Seminars are presented twice yearly and last four and one-half days. Attendance generally is limited to 25 people so that an effective level of instruction is maintained. The roster of students usually represents the same types of organizations that make up the lists of calibration customers, except that often there are attendees from foreign countries whose own national laboratories cannot offer such instruction.

The Division offers instruction in pressure measurement as well, through the seminar on Calibration and Use of Piston Gages. This seminar is offered twice yearly to a maximum of 15 people at each session. B. E. Welch is the prinicpal instructor.

C. Consultations

Frequently it happens that the Division is asked for advice on measurement problems that are very specifically related to a particular company or industry. Such requests can be resolved many times during a telephone conversation or by a visit to NBS by the scientist or engineer making the request, but occasionally effective help can be given only through a longer-term effort on behalf of the caller. As examples of such assistance by the Division, we can cite the following activities from the past year:

*A one-day visit to the Orton Foundation by an NBS measurement consulting team which included G. W. Burns. The Orton Foundation is a major supplier of pyrometric cones used in heat treating;

*Development of a level sensor by V. E. Bean and F. G. Long for the Bruceton, Pennsylvania, DoE facility [16]. Originally thought to be a pressure measurement problem in the handling of liquid coal derivatives, this effort took the form of a magnetic level sensor in the output line of a coal reactor. The design has been described in a report to sponsor and is under patent consideration;

*Continuation of a long-term effort on behalf of the heavy metals industry by G. W. Burns and G. A. Evans. The principal objective of this project is the development of a test method for disposable thermocouple thermometers used in preparing melts of heavy metals. Currently the work involves an effort to measure the melt temperature for continuous periods of 20 minutes or more. This work is described more fully in a later section of this report;

*Advice to a manufacturer of piston gages on technical design; and

*A one-day visit by G. W. Burns to the Owens-Corning Corporation to review plant temperature measurement techniques.

## III. DEVELOPMENT OF NEW STANDARDS FOR TEMPERATURE AND PRESSURE MEASUREMENT

At the present time there is an intense effort on the part of the TPMSD to develop new standards for temperature measurement. This work is part of a world-wide effort to replace the International Practical Temperature Scale of 1968 with a scale which is both improved and extended in range. The international Consultative Committee for Thermometry, acting under the direction of the International Committee for Weights and Measures, is monitoring the progress of the current research and has the responsibility for preparing the text of a replacement scale. Discussions of this international thermometry effort have been published in the NBS Dimensions magazine (September 1978 and November 1980 [32]); these articles have been circulated to many interested persons during the past two years.

Besides the effort in international standards for temperature, the Division staff also is active in U.S. industrial and medical temperature standards.

International standards of pressure exist primarily in the form of standard instruments; however, there is a growing interest in the establishment of a pressure scale. As with temperature, the development of industrial standards of pressure continues to be actively pursued.

### A. Work Towards A New Temperature Scale

The IPTS-68 provides for the measurement of temperature over the range 13.8 K to 904 K (-259 °C to 630 °C) by use of a standard platinum resistance thermometer (sPRT) calibrated at prescribed reference temperatures. The main objective in formulating the IPTS-68 was to provide reproducible, precise temperature measurements for the use of science and industry; in the sPRT range this objective has been realized rather well. In the hands of careful workers, the typical level of imprecision for sPRT's over most of their range does not exceed a few tenths of a millidegree, which amounts to about one part per million at room temperature. Much larger temperature errors are introduced by differences in the IPTS-68 fixed-point realizations in different laboratories. For this reason, the major research on thermometry in this range is focused on more reproducible fixed-point devices [22].

#### 1. Sealed Triple-Point Cells

Outstanding among improved temperature fixed-point devices is the sealed cell for realizing the triple points of low-temperature gases. At the NBS, this type of cell is under study by G. T. Furukawa. His work is part of an international effort to develop transportable, precise, and practical cells for use below room temperature. Cells containing Ar, $O_2$, $CH_4$, $H_2$, Kr, and Xe have been prepared in various countries as part of this program. Shown below are results obtained with two sPRT's by Furukawa on melting a sample of Ar in a sealed cell. This figure shows that the sPRT measurement precision, as well as the cell temperature stability, approaches 0.01 millikelvins.

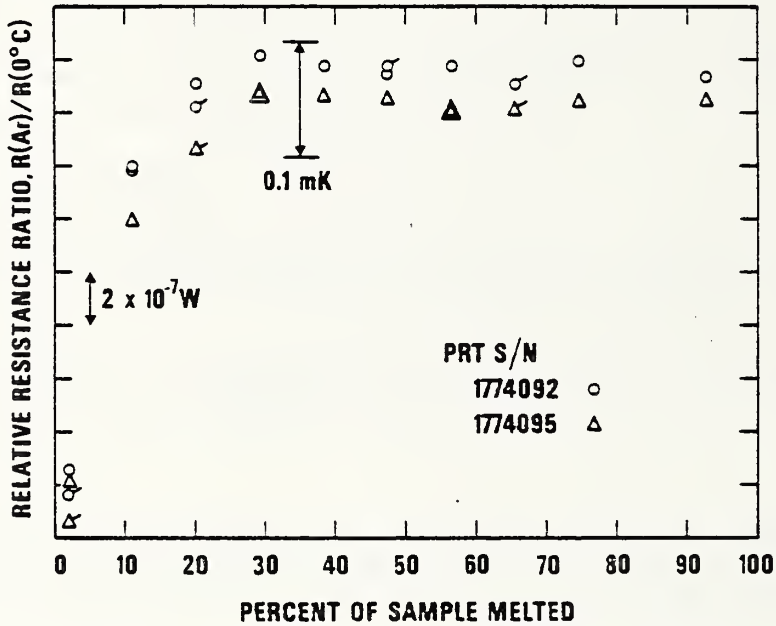


Fig. 1: Melting curve of Ar in a sealed cell. The curve was measured with two thermometers.

Measurements made on Ar cells prepared by several different laboratories show a mean value of 83.8003 K and a spread of about 0.2 mK. These results indicate that such a cell can provide a very precise reference temperature without the usual problems associated with contamination and manometry that are found using open cells.

Using a sample of 99.9995% pure $O_2$, Furukawa found an IPTS-68 triple-point temperature of 54.3619 K. The melting curve showed discernible effects of impurities, however, so that Furukawa plans to prepare more pure oxygen by decomposing $KMnO_4$ during the coming year.

Furukawa has obtained samples of Kr and Xe for similar studies. In addition, he is modifying a calorimetric cryostat for measurements below 50 K.

2. Triple Point of Water

The triple point of water is the primary defining point of the Kelvin thermodynamic temperature scale and of the IPTS-68. This temperature is ordinarily realized using sealed re-entrant cells of borosilicate glass. It is difficult to exclude air, however, during the construction of water triple-point cells. In order to determine the effects of air or impurities leached from the glass by the water, Furukawa tested a collection of 16 cells ranging in age from newly purchased to more than 20 years. The triple-point temperature of 15 of the cells agreed within ±0.03 millidegrees Celsius. The 16th cell showed a triple-point temperature some 0.15 millidegrees lower, probably as a result of contamination with air; examination of the cell revealed a noncondensible bubble about 2 cc in volume. Thus Furukawa estimates that triple point of water cells are capable of thermometric precision within about 30 microdegrees Celsius (about 2 parts in ten million).

3. Gallium triple point

In an earlier report, B. W. Mangum noted that the melting curves of high-purity samples of Ga showed stability at the 1 microkelvin level when the samples had been prepared for determination of the triple-point temperature. During the past year, Mangum experimented with the use of teflon-coated stainless steel cells on the ground that they would be more safely transported than the all-nylon cells used originally. Both ac and dc resistance bridges were used to measure the sPRT's. Final results are not available, but the preliminary findings indicate the presence of pinholes in the teflon coating of some of the cells and that the mean triple-point temperature of the newly-prepared cells agrees well with the earlier determination.

4. Resistance Thermometer Bridges

The IPTS-68 text does not prescribe the measurement method to be used in realizing the scale. In various laboratories, measurements of sPRT resistances are made with potentiometers, current comparators, dc resistance bridges, and ac resistance bridges. The NBS issues sPRT calibrations based upon dc Meuller bridge measurements, although a 400-Hz ac bridge designed by R. D. Cutkosky and a commercial current comparator are under study as well.

Recently, Cutkosky has designed a new resistance bridge [2]. It uses 15 Hz or 30 Hz square wave excitation, is self-balancing, and incorporates a microprocessor control for full compatibility with computer-based, automatic operation. Several measuring currents are available, and the bridge has been modified for use with guarded thermometers [3] and resistances as high as 100 ohms.

During the past year, three bridges of this design were built under the direction of Cutkosky and R. S. Kaeser, bringing the total number in the Division to six.

## 5. Temperature Scale Improvement above 900 K (630 °C).

In the IPTS-68, temperatures between 900 K and 1337 K (respectively the Sb and Au freezing points) are determined by use of thermocouple thermometers, resulting in a marked deterioration of the scale precision. To improve thermometry in this range, J. P. Evans has spent many years in an effort to design and fabricate platinum resistance thermometers capable of the greatest stability and precision at temperatures as high as 1370 K (1100 °C). During 1980, with the help of R. D. Cutkosky, Evans designed a guarded-lead thermometer in an attempt to reduce the effect of leakage currents in the 2.5-ohm configuration. The guarding technique proved to be effective, but most of the 1980 thermometers were unsatisfactory in stability, apparently because of contamination of the platinum resistor during construction.

During 1981, an additional 25 thermometers were built, including five by H. Nubbemeyer of the PTB in Berlin and ten by N. Bass of the CSIRO in Sydney. In general, the alpha coefficient was found to decrease on heating to 1100 °C from an initial value above 0.003926 to a value lower than 0.003925 (the lower limit of alpha for a sPRT). Elimination of a teflon separator in the thermometer head, replacing the argon-10% oxygen filling gas with dry air, and prolonged annealing at 900 °C all proved ineffective in correcting this decline in the alpha coefficient. Chemical testing of the affected thermometers has indicated the presence of copper; accordingly, the glass-cleaning procedure has been modified slightly, and a second bake-out system has been installed for use with newer thermometers. Results are not yet sufficient to judge the efficacy of these steps.

Several modifications to the thermometer geometry have been made as well. One thermometer resistor was fabricated in a coiled helix configuration; its alpha value remained above 0.003925 after 700 h above 1100 °C. In another change, two thermometers were made with grooved cylindrical fused silica resistor mounts; however, the rate of change of the triple-point resistance was anomalously large for these thermometers. Finally, several thermometers were prepared using crosses with 20% deeper notches for the windings, again with no improvement in characteristics.

During the past year, the NIM in Peking gave the NBS a 0.25-ohm high-temperature PRT of Chinese construction. Preliminary examination shows an alpha value of 0.003927 and essential agreement with the resistance-temperature relation of the NBS thermometers up to 660 °C.

J. P. Evans also has been working on the problem of improving the precision obtainable with Ag and Au freezing points. He has fitted a silver point cell with a heat pipe; a recent modification of this arrangement has produced a cell with a 5-cm length uniform within 0.1 mK except for the hydrostatic head gradient.

## 6. Temperature Scale Improvement Below 30 K

NBS contributions to the extension of the IPTS-68 to lower temperatures include the development of superconductive temperature reference points, the evaluation of the 0.5 K to 30 K Provisional Temperature Scale (EPT-76), development and evaluation of cryogenic thermometers, and the evaluation of thermodynamic temperatures [20].

Little progress was made in renewing the SRM 767 0.5 K to 7 K superconductive fixed point device during the past year; G. A. Evans has been returned to the project on a half-time basis to prepare single-crystal samples and J. F. Schooley has rebuilt a cryostat in which the devices can be tested at the 0.1 mK level of resolution.

The SRM 768 device continues to be produced by R. J. Soulen and R. B. Dove. The principal activity during the past year in this regard has been the use of the SRM 768 to resolve a controversy about the He-3 phase diagram. This work took place in Finland; essentially, the Be and W points of the SRM 768 were employed to calibrate a Pt nuclear magnetic resonance thermometer and verify within 2% the assignment of 1.04 mK as the temperature of the zero pressure point on the phase diagram [34].

E. R. Pfeiffer and R. S. Kaeser compared values on the EPT-76 obtained from several sources; two capsule PRT's calibrated on the IPTS-68, four germanium resistance thermometers calibrated on the NBS Provisional 2-20 K acoustic temperature scale of 1965, two Rh-Fe resistance thermometers calibrated on the NPL-75 gas thermometer scale, and two NBS SRM 767 devices augmented by a paramagnetic salt thermometer containing cerous magnesium nitrate. The results obtained in this study indicate agreement between the various realizations of the EPT-76 within about 1 mK. A novel feature of this work is the use of a computer-based system for control of the experiment as well as for obtaining and processing the data.

No practical thermometry technique capable of 0.1 mK reproducibility at all temperatures between 0.5 and 30 K has yet been demonstrated. In principle, gas thermometry should be appropriate in this range, since the ideal gas law would permit relatively accurate interpolation between relatively few fixed reference temperatures; in practice, however, the problems in performing manometric measurements have been a sufficiently strong disadvantage to discourage use of this method. C. T. Van Degrift recently devised a new type of gas thermometer in which a single electrical lead conveys information on the resonant frequency of an LC oscillator circuit employing a cryogenic tunnel diode. During the past year, six copies of a successful prototype gas thermometer have been fabricated from coin silver. The thermometers have been made with capacitor diaphragm thicknesses varying from 0.1 mm to 9.25 mm. The corresponding predicted temperature resolutions of these units vary from 3 to 50 microkelvins.

Evaluation of thermodynamic temperatures by noise thermometry and gamma-ray anisotropy thermometry at the NBS has permitted the evolution of a new low-temperature scale, the NBS-CTS-1, from 0.01 K to 0.5 K [13,34,35]. During the past year, R. J. Soulen, with the assistance of H. Seppa, a Finnish Guest Worker, and of W. S. Hurst, has succeeded in accelerating the acquisition of data by about a factor 100. This improvement should materially reduce the uncertainty of noise temperatures obtained in Soulen's laboratory. In a neighboring laboratory, H. Marshak has performed many of the preliminary measurements necessary to use Ho-166m [8] as a gamma-ray thermometer in the range 35 mK to 1.2 K.

Most of the projects reported in this section will be the subjects of papers to be presented to the 6th Symposium on Temperature, Its Measurement and Control in Science and Industry.

B. Industrial and Medical Temperature Standards

Besides work on research leading to a replacement for the IPTS-68, the Division is involved in the work of industrial and medical standards of temperature. Much of this work occurs at the behest of Committee E-20, Temperature Measurement, of the American Society for Testing and Materials or of the National Committee for Clinical Laboratory Standards.

At the request of the resistance thermometry subcommittee of the ASTM E-20 Committee, G. T. Furukawa has undertaken a round-robin series of evaluations of the calibration capabilities of industrial laboratories. Results of the first year's measurements indicate that an sPRT is the most satisfactory thermometer for this evaluation. Although the sPRT's receive sufficiently rough handling in the tests that the thermometer resistance changes by amounts corresponding to 0.05 K to 1 K, the resistance ratio W changes only by relatively small amounts, 3 mK to 5 mK. To obtain information on the behavior of industrial PRT's, some 40 thermometers were obtained from different manufacturers for tests at the triple point of water and at the Sn and Zn freezing points. Furukawa also serves the ASTM E-20 as secretary of the New Thermometers Subcommittee, and he has written a draft standard on fixed points and assisted in the preparation of a standard on industrial PRT's. In addition, Furukawa has agreed to help write a handbook on resistance thermometry.

On behalf of a Task Group on Immersion Thermocouples for Molten Metals, G. W. Burns, with the assistance of G. A. Evans, has designed new thermocouple thermometer probes intended to function for 15-20 min in molten metal at temperatures of 1400 °C and 1650 °C. During the past year, two such probes were built. These probes incorporate Type B thermocouples (Pt-30% Rh vs. Pt-6% Rh) insulated with high-purity $Al_2O_3$ and protected by a self-bonded Type KT SiC sheath 13 mm o.d. and 0.6 m long. The SiC sheath is joined to a 2.2 m long stainless steel sheath which itself is protected by multiple wrapping of "Fiberfrax 800" paper.

Burns also designed and constructed a crucible for preliminary testing, and found that the SiC suffered severe attack after only 3-6 minutes in molten iron. As a consequence of these tests, the protective sheath has been redesigned to incorporate Mo tubing which is spray coated with $MgAl_2O_4$.

During the past year, also, the second edition of the ASTM STP 470B "Manual for the Use of Thermocouples" was issued. Mr. Burns again served as a co-editor for this work.

The Temperature and Pressure Measurements and Standards Division staff is participating in the development of measurement standards in support of resource recovery, under the direction of the NBS Office of Recycled Materials. The role of the Division is to provide assistance in the development of thermometry for use in high-temperature industrial combustion. M. L. Reilly, in collaboration with colleagues in the NBS Center for Chemical Physics, has made considerable progress toward the development of a large scale calorimeter for use in evaluating the calorific value of industrial waste. This device is a flow calorimeter designed for 2.5 kg samples. The first draft of a manuscript describing experiments with a prototype combustor and the analysis of the experimental data was finished during the past year. Other Division staff members contributed to the project by providing advice on materials, thermometry, and data acquisition techniques for the large-scale calorimeter, and by work on ancillary high-temperature instrumentation involving thermocouples, high-temperature resistance thermometers, and temperature reference devices.

The Division's Medical Thermometry project, led by B. W. Mangum, showed accomplishments in several areas during the past year. Characteristics of about 80 small platinum RTD's (resistance temperature detectors) from 5 companies were studied over the range 0-100 °C; the stability of the thermometers' resistances following thermal cycling to 250 °C was evaluated. In another study, the behavior of Rb as a temperature fixed point was examined. Rb proved to be a difficult substance to handle in the NBS laboratory, so that the assistance of a commercial firm was obtained to fill some of the stainless steel cells used to hold Rb samples. Preliminary results indicate that a temperature accuracy of ±0.01 °C can be obtained with the use of cells such as these. Other fixed points in the range of interest for medical thermometry include transitions in hydrated salts [7], succinonitrile (triple point about 58 °C), and In (melting point 156 °C); samples of both these latter substances are under study. The Medical Thermometry project benefitted this year from the work of G. A. Evans and of J. M. Figueroa, a Guest Worker from the Polytechnical University in Mexico City.

C. International Standards of Pressure and Vacuum

During the past year, a new consultative committee was formed under the auspices of the International Committee for Weights and Measures.

It is called the Consultative Committee for Mass and Related Quantities. Its initial meeting at the International Bureau of Weights and Measures took place in June 1981. This Committee discussed current and proposed activities involving international standards for pressure and vacuum, including the following:

*International comparison of piston gages in the range of atmospheric pressure. This comparison will use 50-psi CEC gas-operated gages provided by the NBS;

*International comparison of piston gages in the 100 MPa range (15,000 psi), using an oil-operated gage from France;

*International comparison of low pressure gages; NBS is the pilot laboratory for this work, which will involve the use of capacitance diaphragm gages.

The Division staff members responsible for coordinating CCM work in pressure and vacuum are respectively, V. E. Bean and C. R. Tilford.

Several years ago, the International Association for the Advancement of High Pressure Science and Technology (AIRAPT) organized a task group with the responsibility for studying an international high pressure scale. V. E. Bean is the chairman of this task group. This year he wrote a review of high pressure metrology with recommendations regarding a high pressure scale, and circulated it within the committee for discussion during the August 1981 meeting in Uppsala [17].

D. New NBS Pressure and Vacuum Standards

The principal activity in the improvement of pressure standards at the NBS is the calibration of 3 CEC gas-operated piston gages against the NBS Gas Thermometer manometer. It is expected that the 1.5 ppm pressure accuracy of the latter can be utilized to improve substantially the primary piston gage accuracy at pressures near one atmosphere. Subsequent cross-checking among the CEC gages should preserve the improved accuracy, and it is hoped that cross-calibration with higher-pressure gages will improve their accuracy ratings as well [29]. The gages have been acquired for this experiment, and mounting hardware to operate them in the absolute mode is nearly complete. B. E. Welch, R. G. Driver, and L. A. Guildner are working on this project.

New 3000 psi controlled-clearance primary standard piston gages have been ordered. These gages will be used in the calibration service once they have been characterized.

Results obtained over the past two years by B. E. Welch on a heavily-instrumented piston gage cylinder have given a great deal of information on fluid properties in the annular crevice between the piston and cylinder. A typical plot of some of this data is shown at the top of the next page.

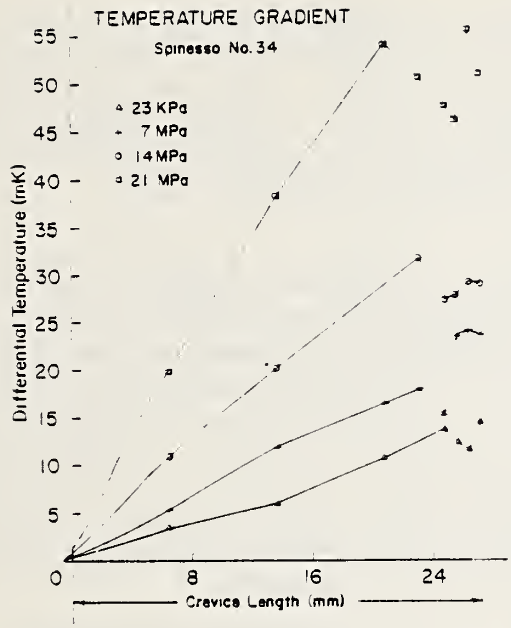


Fig. 2: Temperature gradient in the annular space between a piston and cylinder of an oil-operated piston gage using "Spinesso No. 34" as the working fluid. The temperature anomalies appear to be related to dimensional changes in the annulus.

A paper discussing these results is in preparation. This experiment is the first of its kind; it has yielded the following interesting information:

*The data support a model proposed by Bass of the NRC in Canada;

*The elastic distortion coefficient probably can be calculated from dimensional measurements;

*The position of the effective seal in a piston and cylinder can be located by dimensional measurements; and

*Data were obtained on the effect of viscosity on the temperature and pressure profiles in the annular gage crevice.

A project originated some time ago on the measurement of pressure by capacitance has been reactivited following the rejoining of J. H. Colwell to the Pressure Group. A major difficulty of using capacitors for pressure transduction lies in their large temperature sensitivity. Progress to the present time has followed the use of two capacitors in opposite arms of a capacitance bridge; if the dielectric materials of the two capacitors have nearly identical temperature dependences but different pressure dependences, a workable gage can result. One such pair of dielectric materials is composed of two different orientations of crystalline calcite; a second pair results from the use of bismuth germanium oxide and arsenic trisulfide. The value of this work lies in the possible applications as a stable transfer standard to save wear on the primary pressure standards and as a sensitive pressure monitor in the characterization of controlled clearance gages.

Effort was made this year to improve the ultrasonic interferometer manometer, which is used for calibration in the 0.1 Pa to 0.1 MPa range. R. W. Hyland has incorporated an on-line computer capability to reduce the time spent on data analysis and to speed diagnostics, and F. W. Long and Hyland have modified the rf electronics and microprocessor control circuitry to improve control of the instrument. The manometer was used for more than twenty calibrations this year. It also served to evaluate a low-range dead-weight ball gage, confirming a significant non-linearity noted previously. The usefulness of the ultrasonic manometer was recognized by the presentation of a 1981 IR-100 Award to the NBS staff, including P. L. M. Heydemann, C. R. Tilford, R. W. Hyland, D. F. Martin, and F. G. Long.

A new gage comparator for the high vacuum range (0.1 mPa to 0.1 Pa) was completed during the past year by K. E. McCulloh, D. F. Martin, and C. R. Tilford. A service in the calibration of ion gages was begun using this device in conjunction with standard gages from the NPL in England and from the PTB in Germany. Work is under way to develop a primary vacuum standard for this range by constructing a flowmeter for use with the vacuum comparator.

A major effort in the characterization of high vacuum gages was begun this year by C. R. Tilford and K. E. McCulloh. The problem with these gages is that their metrological properties have not been adequately determined. The first step in evaluating the factors that affect gage accuracy was to observe the response of several commercial gages to nitrogen gas; a paper on this topic was published this year [11]. With the assistance of an NBS Research Associate from Korea and of a summer student, further examination of widely-used commercial gages was accomplished. Shown at the top of the next page is a graph of some of these results.

A further problem in the use of ion gages has been the relatively unstable performance of commercial ion gage controllers. McCulloh and F. G. Long have designed and built a new controller. It is now in routine use in the project; when the final design is fixed, it will be published.

E. Thermodynamic Properties of Moist Air

R. W. Hyland had considerable experience in the field of humidity measurement prior to joining the Pressure Group. An outgrowth of that work

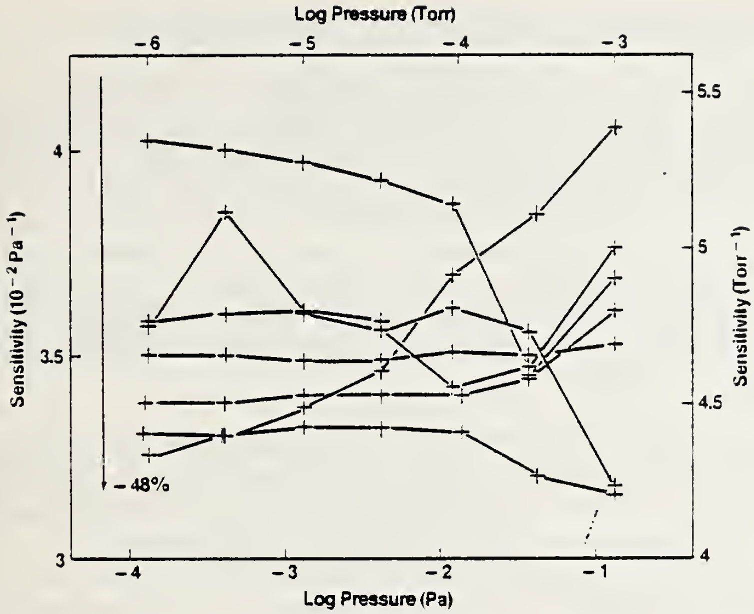


Fig. 3: Nitrogen sensitivities for seven different ion gages as a function of pressure.

has been the development of comprehensive formulations for the properties of the air-water system under the auspices of the American Society for Heating, Refrigeration, and Air Conditioning Engineers. Writing has been completed during this year for three publications on this work [24,25,26].

F. Industrial, Medical, and Fusion Pressure and Vacuum Standards

The Division staff serves the pressure and vacuum industrial standardization community by participating in the work of the American Society of Mechanical Engineers and the American Vacuum Society. V. E. Bean attended a meeting of an ad hoc committee on High Pressure Vessels and Piping of the ASME during the past year; C. R. Tilford currently is the chairman of the Standards Committee of the AVS and consults with the ASTM Committee E-21.04 on Space Simulation; R. W. Hyland is chairman of the Gaging Subcommittee of the AVS Standards Committee.

The Vacuum Group has made some progress during the past year toward completing a vapor pressure apparatus for use in research at the National Institutes of Health.

The Vacuum Group is involved in a substantial collaborative project on behalf of the DoE Magnetic Fusion program. This year the NBS work included calibration of vacuum gages used in vacuum pumping speed measurements at the Los Alamos Scientific Lab and the evaluation of the LASL measurement techniques. The NBS analysis showed several problem areas in these measurements. Solutions to these problems will be pursued, since an improperly-designed pumping system can lead to major financial and technical penalties. A co-op student has been added to this project.

## IV. RESEARCH IN TEMPERATURE, PRESSURE AND VACUUM PHYSICS

The Division supports considerable laboratory work in which the typical output is a scientific paper on the properties of matter or demonstration of a new measurement technique rather than a calibration or a new standard device or procedure. It is felt that the scientific growth of the Division staff accompanying such broadly-based and undirected research enables staff members to develop or understand new principles for the precise measurement of temperature, pressure, and vacuum. This approach has been proven useful over a long period of time during which NBS has made major contributions to the development of precision measurement in these areas.

Because the staff involved is inevitably aware of the close relationship of their work to the development of new standards, it is often difficult to categorize specific projects as "basic" or "undirected". Nevertheless, the existence of such projects is demonstrably of fundamental importance to the long-term success of a metrological division, so that work not specifically devoted to the development of new standards is encouraged to the extent that flexibility in the program permits it.

### A. Optical Measurements of Temperature and Pressure

G. J. Rosasco, with assistance from W. S. Hurst and R. B. Dove, is preparing the apparatus necessary to measure the shifts and widths of the levels of molecules such as $N_2$, $O_2$, CO, and $CO_2$ as functions of pressure at room temperature. These data are not available, and they are fundamental to the use of such information to characterize the temperature and pressure of gaseous systems at high speed and without the imposition of contact sensors. The project plan is to measure these properties with very stable, narrow-frequency cw-laser sources.

The experimental apparatus involves several sub-systems which are in various stages of construction. Among them are a frequency-stabilized continuous krypton ion laser to be used as a "pump" -- to prepare a population of molecules in excited states; a single-frequency continuous ring dye laser to be used as a probe of the excited population (states are selected by adjusting the pump-probe frequency difference); a frequency measurement system; an optical detection system for use in wide-band detection; optically-resonant sample cells; a computer-based data acquisition and control system; and, for use in future high-temperature experiments, a pulsed dye laser.

Work on this project during the past year has focussed on the design of the first experiments and the acquisition and construction of the basic instruments to be used. Considerable benefit is expected from the contiguity of this laboratory to that occupied by collaborating staff of the Molecular Spectroscopy Division.

B. <u>Physics of Superconducting Films and Josephson Junctions</u>

R. J. Soulen, with the assistance of R. B. Dove and collaborating with D. Van Vechten, an NBS Postdoctoral Research Associate, and with L. B. Holdeman of the NBS Electrical Measurements and Standards Division, is involved in several projects besides the evaluation of thermodynamic temperatures by Johnson noise measurement described elsewhere in this report.

Considerable progress has been made in understanding the impedance of resistively-shunted superconducting quantum interference detectors (SQUID's). Van Vechten has studied the dependence of the impedance upon the impressed dc current, the bias amplitude, and the frequency of an rf bias; and H. Seppa, a Guest Worker from the VTT laboratory in Helsinki, has succeeded in correlating these results with an improved model of the R-SQUID. These results are shown below.

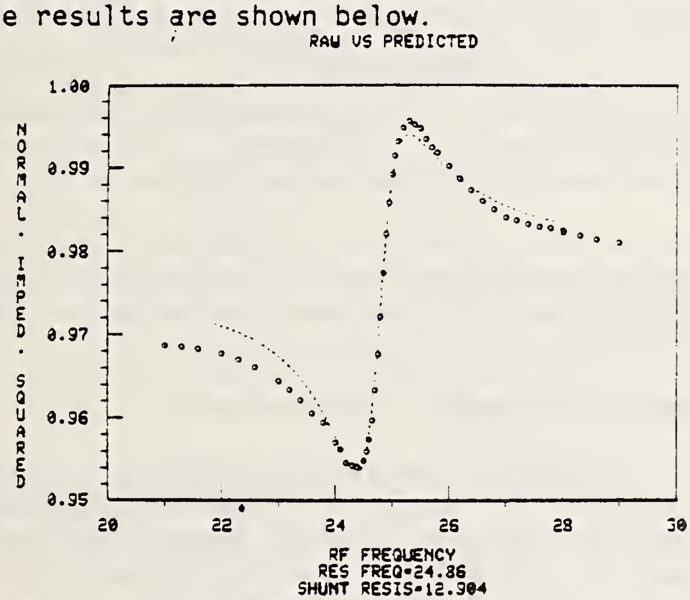


Fig. 4: Fit of the impedance of an R-SQUID to the RF input frequency. The circles show the data and the dashed line represents the calculated impedance.

In another project, which receives partial support from NASA, Soulen, Van Vechten, Holdeman and J. T. Hall, a former NBS Postdoctoral Research Associate, are investigating the effect of microwave radiation on tunnel junctions [39]. Last year's short report on microwave enhancement of the superconducting energy gap [6] has been followed during this year by measurements on high-quality tunnel junctions of aluminum and $AuIn_2$ or $AuAl_2$. The current measurements were of the energy gap as a function of temperature; the fit to that calculated from the BCS theory was quite good. It was reported during the 16th Low Temperature Conference [36]. Microwave irradiation experiments are inhibited by substantial heating of the cryostat, indicating the necessity for improved microwave leads.

Soulen, P. H. E. Meijer, and R. D. Mountain, of the NBS Thermophysics Division, conducted the 6th International Conference on Noise in Physical Systems in April of this year. The proceedings will be published as an NBS Special Publication during September of 1981 [28].

C. Nuclear and Magnetic Studies in Holmium

Single crystals of holmium are used by H. Marshak in the development of nuclear orientation thermometry, as is described elsewhere in this report. The generation of Ho-166m nuclei by neutron capture within such a crystal is straightforward because holmium has only one stable isotope, mass 165. The nuclear decay scheme of Ho-166m has not been completely determined, so that this isotope cannot be used at present to obtain thermodynamically meaningful temperatures. To develop Ho-166m in holmium as a fundamental thermometer, Marshak has undertaken the problem of determining the multipolarity mixing ratios for some 27 gamma-rays in this nuclide [8]. By measuring gamma-ray anistropies in a Ho single crystal under conditions of nearly complete nuclear ordering, Marshak can assign mixing ratios with unprecedented accuracy (by perhaps a factor of ten better than previous assignments). These results will be prepared for publication during the coming months.

The study of the magnetic structure of holmium is complete [10]. A paper entitled "Nuclear Orientation Studies of Multiaxial Nuclear Spin Systems: Ho-166m Ho" will be published soon in the journal Hyperfine Interactions [27].

D. Thermodynamic Measurements on Solid He-3

C. T. Van Degrift, with the assistance of W. J. Bowers, has been engaged for some time in a study of the thermodynamic properties of solid He-3. The apparatus in use is a pulsed tunnel diode oscillator pressure cell contained in a He-3-He-4 dilution refrigerator.

Progress during the past year included measurements of the pressure of solid He-3 at temperatures as low as 30 mK and pressures as high as 3.2 MPa in magnetic fields up to 8 tesla; measurements of the magnetothermal conductivity of coin silver (a useful material for many low-temperature, high-field applications) [38]; and measurements of the melting curve of He-3. Partial phase diagrams for He-3 and He-4 are shown at the top of the next page.

A significant improvement in the tunnel diode oscillator sensor [14] was required for the He-3 work. By operating the resonator in a pulsed mode (0.03 sec per pulse), its power dissipation was reduced by a factor of 100 while the frequency resolution remained at one part in $10^8$ [37]. This modification also demonstrated the practicality of rapid scanning of a large number of such sensors. In addition, the detailed behavior of the pulsed oscillator was examined by use of a full computer simulation, and

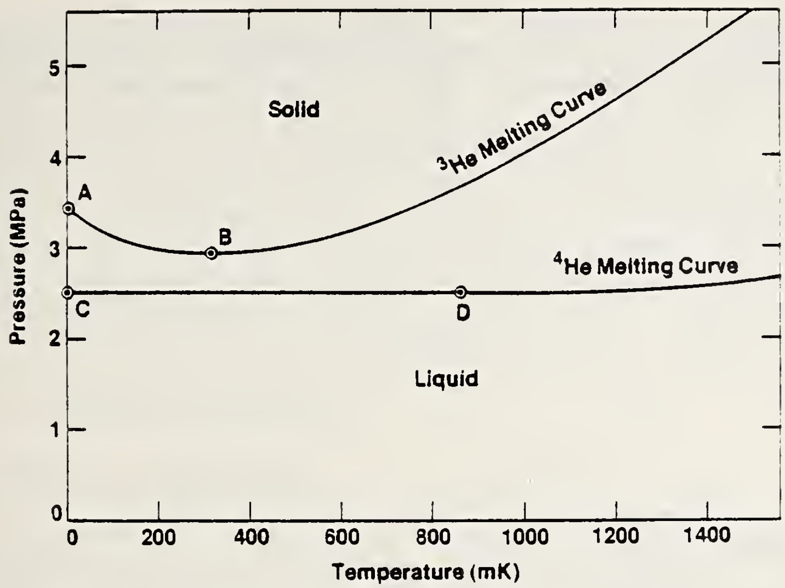


Fig. 5: Melting curves for He-3 and He-4 up to 1.4 K.

general rules were developed governing the fundamental limits of the technique ($10^{-8}$ parts resolution in 100 μs).

A calibration of the low temperature sensor against a room temperature piston gage with the assistance of G. Driver led to a paper describing the present utility of this project for assisting pressure standards work by providing stable sensors and reproducible fixed points and the prospects for future pressure standards based on cryogenics.

E. <u>Properties of Materials at High pressures</u>

Several experiments on the properties of materials at high pressures [15] are in progress, all involving V. E. Bean and S. D. Wood. One of these is a study of the compressibility of fluids -- a good understanding of this property is necessary for all materials to be used in fluid-operated piston gages. During the past year, new sample cells designed for use at pressures up to 1.4 GPa were constructed. The design was intended to permit direct evaluation of the fluid compressibility by simultaneous measurement of the capacitances of two samples of the test fluid, one held at constant volume and the other maintained with a constant number of molecules.

A secondary cell was especially designed for use with $CCl_4$, which has been shown to possess two metastable phases. In this cell, the $CCl_4$ is contained in a stainless steel bellows, the length of which is measured by capacitance. Preliminary analysis of the experimental data indicates that an equation of state for $CCl_4$ can be constructed to cover the range of temperature from -19 °C to 25 °C and pressures up to 200 GPa. In addition, information has been collected on the $CCl_4$ compressibility over the same ranges; the changes of volume accompanying the fcc-rhombohedral, the liquid-fcc, and liquid-rhombohedral phase transitions and their enthalpies and entropies; and on other anomalies in the $CCl_4$ properties. The compressibility of $CCl_4$ at -19 °C is shown below.

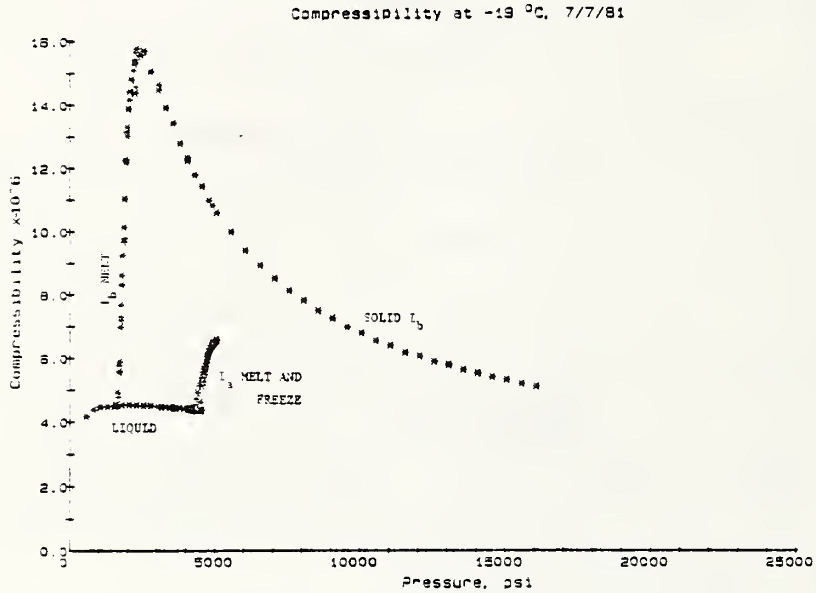


Fig. 6: Compressibility of $CCl_4$ at -19 °C for pressures up to 20000 psi. The curve $I_a$ refers to the face-centered cubic phase and the curve $I_b$ refers to the rhombohedral phase.

Also constructed during the past year was a viscometer designed for use up to 1.4 GPa at room temperature. The work of a summer student, M. Turner, was utilized in a search for a fluid possessing a usefully high low-pressure viscosity in conjunction with a pressure dependence of viscosity which is lower than logarithmic. Initial choices for study have been glycerine and several alcohols.

A three-year cooperative research program between the NBS Pressure Group and researchers at the U. S. Naval Academy, J. Fontanella and M. Wintersgill, was completed during the past year. Among the results of this collaboration are the following:

*Dielectric properties of $CCL_4$ from -14 °C to 21 °C and up to 200 MPa [1]. This study provided information on the normal fluid, the metastable fluid, and both of the solid phases, and preliminary analysis indicates that the Clausius-Mosotti equation holds not only for the dielectric properties of the normal fluid state but also for the super-pressed, metastable fluid state;

*Study of the dielectric properties of another plastic crystal system, cyclohexane in the fcc solid phase. Unlike $CCl_4$, cyclohexane appears not to possess a super-pressed fluid phase;

*Study of the rotator-nonrotator phase transition in cyclohexanol, under examination as a possible pressure fixed point. Preliminary results indicate that the transition is not reproducible;

*Development of a solid dielectric material for use in pressure transducers. As noted elsewhere in this report, such a material should possess a large pressure coefficient and a small or zero temperature coefficient of capacitance. By adding Er to $CaF_2$, its usual temperature coefficient was markedly diminished, while its dielectric constant and the pressure coefficient were increased by factors of three and 1.16, respectively. Further work will be done on this material by J. H. Colwell.

## V. GENERAL DIVISION ACTIVITIES

### A. Laboratory Automation

During the past few years it has been possible for the Division to spend substantially more funds for capital equipment. Much of these funds have been utilized for the purchase of laboratory minicomputers and the associated components, as well as for computer-compatible measuring instruments. As a result, the Division has made considerable progress in the use of computer-based data acquisition and control equipment both for research and for calibration.

W. S. Hurst has provided much of the concentrated effort needed to establish the requirements for a given application and to assist the affected staff members in acquiring suitable systems, although by no means has he worked alone on this problem. Other staff members contributing to the generation of hardware and software requirements within the Division include R. S. Kaeser, F. G. Long, M. L. Reilly, and S. D. Wood.

During the past year, several new computer applications have been introduced. These include:

*Use of a computer to record and analyze data on the compressibility of $CCl_4$ and the introduction of real-time plotting to that experiment;

*Introduction of a minicomputer to control the operation of in the ultrasonic manometer and to record the data from this instrument;

*Introduction of a minicomputer-based data acquisition system into the thermocouple calibration laboratory;

*Full use of a minicomputer to control fixed-point equipment in the high-temperature resistance thermometer laboratory, and automatic measurement and processing of thermometer resistances using the new 15-Hz Cutkosky resistance bridge;

*Acquisition of a minicomputer in conjunction with a 100-ohm Cutkosky resistance bridge for evaluation in the sPRT calibration laboratory;

*Refinement of the automatic temperature control and data acquisition and processing system in use in the low-temperature scale laboratory. The "MOOSE" control program was improved and expanded to allow 50 different measurement tasks, and a new 15-Hz Cutkosky bridge was coupled to the apparatus;

*Installation of a computer-based data acquisition and control system in the optical temperature and pressure measurements laboratory; and

*Installation of a new computer and frequency counter system in the noise thermometry laboratory.

B. <u>6th Temperature Symposium</u>

Serious work was begun during the past year to prepare for the 6th Symposium on Temperature, Its Measurement and Control in Science and Industry, scheduled for the week of 14-18 March 1982 in Washington, DC. This decennial symposium will be co-sponsored by the NBS, the Instrument Society of America, and the American Institute of Physics. The NBS responsibility is for the technical quality of the program and of the resulting proceedings, the ISA is responsible for facilities management of the symposium and the attendant instrument exhibit, and the AIP intends to publish the proceedings of the symposium.

Eleven members of the Division staff help to comprise the symposium program committee; J. Schooley is the Program Chairman. Activities thus far include the evaluation of about 200 abstracts of contributed papers and tentative assignment of these topics into symposium sessions.

The preparation of their own technical papers for the symposium, technical review of a substantial portion of the contributed papers, and activities during the symposium itself will occupy much of the Division Temperature group's time during the coming year. However, no comparable source of information on new research in thermometry exists; thus, participation in the 6th Temperature Symposium will provide an excellent opportunity for the Division staff to grow scientifically.

Conferences Sponsored

A joint General Committee and Program Committee meeting was held at the Washington Hilton on 22 June 1981. These committees are planning the 6th Symposium on Temperature which will be held at the Washington Hilton on 14-18 March 1982.

R. J. Soulen, Jr. and P.H.E. Meijer were involved in the Sixth International Conference on Noise in Physical Systems sponsored by the National Bureau of Standards, The Catholic University of America, and the National Science Foundation. The proceedings of this Conference will be published as an NBS Special Publication in September 1981.

Invited Talks

Vern E. Bean, "Metastability in Tetrahidrally Bonded Molecules," Institute of Materials Science, Cornell University, Ithica, NY, 23 July 1981.

Vern E. Bean, "Toward an International Practical Pressure Scale," 8th AIRAPT (International Association for the Advancement of High Pressure Sciences and Technology) Conference, Uppsala, Sweden, 18 August 1981.

J. P. Evans presented an invited talk on high temperature platinum resistance thermometry at a symposium given by the Dayton Section of ISA (Instrument Society of America) at Yellow Springs, OH, November 1980.

G. T. Furukawa, "Temperature Measurements," Symposium for Innovation in Measurement Science (sponsored by ISA), Geneva, NY, 9-14 August 1981.

K. E. McCulloh (C. R. Tilford, co-author), "Nitrogen Sensitivities of a Sample of Commercial Hot Cathode Ionization Gage Tubes," American Vacuum Society 27th National Symposium, Detroit, MI, 14 October 1980.

R. J. Soulen, Jr., "Millikelvin Temperature Standards," 16th International Low Temperature Physics Conference, Los Angeles, CA, 19-26 August 1981.

C. R. Tilford gave a talk on vacuum gaging at the 10th Annual Symposium on Applied Vacuum Science and Technology, Tampa, FL, February 1981.

Seminars Organized

Two Precision Thermometry Seminars -- 9-13 March 1981 and 14-18 September 1981.

Two Seminars on Calibration and Use of Piston Gages -- 15-16 May 1981 and 19-20 November 1981.

Publications - Division 522

In Print:


1. Joseph Link, Mary C. Wintersgill, John J. Fontanella, Vern E. Bean, and Carl G. Andeen, "Pressure variation of the low-frequency dielectric constants of some anisotropic crystals, J. Appl. Phys. 52, No. 2, 936-939 (Feb. 1981).

2. Robert D. Cutkosky, "An Automatic Resistance Thermometer Bridge, IEEE Trans. Instrum. Meas. IM-29, No. 4, 330-333 (Dec. 1980).

3. Robert D. Cutkosky, "Guarding Techniques for Resistance Thermometers," IEEE Trans. Instrum. Meas. IM-30, No. 3, 217-220 (Sept. 1981).

4. R. G. Driver, J. C. Houck, and B. E. Welch, "An Intercomparison of Pressure Standards Between LNE and NBS," J. Res. NBS 84 (5), 277-279 (May-June 1981).

5. G. T. Furukawa and W. R. Bigge, "A Measurement Assurance Program - Thermometer Calibration," *Testing Laboratory Performance: Evaluation and Accreditation*, pp. 137-145, NBS SP-591, August 1980.

6. James T. Hall, L. B. Holdeman, Robert J. Soulen, Jr., "Microwave Enhancement of Superconductivity in Aluminum Tunnel Junctions," Phys. Rev. Lett. 45, No. 12, 1011-1014 (Sept. 1980).

7. R. L. Magin, B. W. Mangum, J. A. Statler, and D. D. Thornton, "Transition Temperatures of the Hydrates of $Na_2SO_4$, $Na_2HPO_4$, and KF as Fixed Points in Biomedical Thermometry, J. Res. NBS 86 (2), 181-192 (Mar.-Apr. 1981).

8. H. Marshak, "Nuclear Orientation of $^{166}$Ho in $^{165}$Ho Single Crystal," Hyperfine Interactions, 10 (1-4), 1183-1188 (June 1981).

9. A. L. Allsop, N. J. Stone, H. Marshak and O. G. Symko, "Nuclear Orientation Studies of $^{54}$Mn in Zn," Hyperfine Interactions, 9/10, 839 (1981).

10. B. G. Turrell and H. Marshak, "Magnetic Structure Determined by Nuclear Orientation," Hyperfine Interactions 10, 1231-1236 (1981).

11. K. E. McCulloh and C. R. Tilford, "Nitrogen Sensitivities of a Sample of Commercial Hot Cathode Ionization Gage Tubes," J. Vac. Sci. Technol. 18, 994 (1981).

12. J. J. Blaha and G. J. Rosasco, "Raman Microprobe Characterization of Urea: $n$-Paraffin Inclusion Compounds," J. Raman Spectrosc. 11, No. 2, 75-80 (1981).

13. E. Lhota, M. T. Manninen, J. P. Pekola, A. T. Soinne, and R. J. Soulen, Jr., "Comparison of the NBS and Helsinki Temperature Scales and Its Effect on the Heat Capacity of Liquid $^3$He Below 10 mK," Phys. Rev. Lett. 47, No. 8, 590-592 (Aug. 1981).

14. Craig T. Van Degrift and David P. Love, "Modeling of tunnel diode oscillators," Rev. Sci. Instrum. 52 (5), 712-723 (May 1981).

14a. J. F. Schooley, "Progress Toward a New Scale of Temperature," NBS Dimensions, November 1980, pp. 10-15.

In Press, in Review, or Nearing Completion:

15. Vincent J. Fratello and Vern E. Bean, "Melting Curve of O-terphenyl," to be published in J. Phys. Chem.

16. Vern E. Bean and Frederick G. Long, Jr., "Coal Slurry Level Monitor Developed," to appear in NBS Dimensions.

17. Vern E. Bean, "Toward an International Practical Pressure Scale," to be published in the Proceedings of the 8th AIRAPT Conference, Uppsala, Sweden, 16-21 August 1981.

18. H. P. R. Frederikse, P. K. Schenck, G. W. Burns, R. R. Dils, and J. R. Whetstone, "Materials for Instrumentation in Fossil Energy," to be published as NBSIR 81-2348.

19. R. D. Cutkosky and R. S. Davis, "A Simple Control Circuit for Temperature Regulation and Other Bridge Applications," to be published in the September issue of Review of Scientific Instruments.

20. G. T. Furukawa, R. S. Kaeser, H. Marshak, E. R. Pfeiffer, J. F. Schooley, R. J. Soulen, and C. T. Van Degrift, "Thermometric Fixed Points Below 0 °C at the National Bureau of Standards," to be published in the Proceedings of Temperature Measurement in Industry and Science, IMEKO TC 12 Symposium, Karlovv Vary, Czechoslovakia, 20-22 October 1981.

21. Furukawa, G. W. Burns, R. D. Cutkosky, R. E. Edsinger, J. P. Evans, L. A. Guildner, and B. W. Mangum, "Temperature Research Above 0 °C at the National Bureau of Standards," to be published in the Proceedings of Temperature Measurement in Industry and Science, IMEKO TC 12 Symposium, Karlovv Vary, Czechoslovakia, 20-22 October 1981.

22. George T. Furukawa, John L. Riddle, William G. Bigge, and Earl R. Pfeiffer, "Application of Some Metal SRM's as Thermometric Fixed Points," to be published as an NBS SP.

23. Leslie A. Guildner and Martin L. Reilly, "Proposed Method for Determination of the Molar Gas Constant, R," to be published in the Proceedings of the Second International Conference on Precision Measurement and Fundamental Constants, Gaithersburg, MD, 7-12 June 1981.

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

25. Arnold Wexler and Richard W. Hyland, "A Formulation for the Thermodyanmic Properties of the Saturated Pure Ordinary Water-Substance from 173.15 to 473.15 K," to be published in ASHRAE Transactions.

26. R. W. Hyland, "Estimates of Uncertainties in Calorimetric Parameters for Pure Water-Substance Determined by Osborne, Stimson, Ginnings, and Fiock in the 1930's," to be published in ASHRAE Transactions.

27. H. Marshak and B. G. Turrell, "Nuclear Orientation Studies of Multiaxial Nuclear Spin Systems: $^{166m}$Ho Ho," to be published in Hyperfine Interactions.

28. P. H. E. Meijer, R. D. Mountain and R. J. Soulen, Jr., *Proceedings of the 6th International Conference on Noise in Physical Systems,"* to be published as NBS Spec. Publ. 614.

29. C. R. Tilford and Donald Martin, "High Sensitivities Gas/Oil Pressure Separator," to be published in Review of Scientific Instruments.

30. R. B. Strem, B. K. Das, W. T. Angel, J. T. Siewick, S. C. Greer and C. T. Van Degrift, "A Digital Temperature Control and Measurement System," to be published in Review of Scientific Instruments.

31. Deborah Van Vechten and Joel F. Liebman, "Number and Novelty in Approaches to the Calculation of Strainless Group Increments," to be published in the Israeli Journal of Chemistry.

32. J. F. Schooley - See Item 14a.

33. K. L. Churney, M. L. Reilly, A. E. Ledford, R. V. Ryan, and E. S. Domalski, "An Oxygen Flow Calorimeter for Solid Fuels", to be published in the Proceedings of the 28th Congress of the International Union of Pure and Applied Chemistry.

The following papers are to be published in the Proceedings of the 16th International Low Temperature Physics Conference, Los Angeles, CA, 19-26 August 1981:

34. E. Lhota, M. T. Manninen, J. P. Pekola, A. T. Soinne and R. J. Soulen, Jr., "Intercomparison of NBS and Helsinki Temperature Scales in the Millikelvin Region".

35. R. J. Soulen, Jr., "Millikelvin Temperature Standards" (Invited paper).

36. Robert J. Soulen, Jr., D. Van Vechten, G. Costabile, Terrence Jach, and L. B. Holdeman, "The Superconductive Energy Gap of $AuAl_2$".

37. Craig T. Van Degrift, "A Pulsing of Tunnel Diode LC Oscillator Sensors".

38. Craig T. Van Degrift, "Coin Silver as a Construction Material in Low-Temperature Experiments".

39. L. B. Holdeman, J. T. Hall, D. Van Vechten, and R. J. Soulen, Jr., "Gap Enhancement in Aluminum Tunnel Junctions Coupled to Microstrip Resonators".

Technical and Professional Committee Participation and Leadership

Vern E. Bean, Chairman, AIRAPT C002, International Association for the Advancement of High Pressure Science and Technology Committee on International Practical Pressure Scale.

G. W. Burns, Member, ANSI C096, American National Standards Institute Committee on Temperature Measurement Thermocouples.

G. W. Burns, Member, ASTM E020, American Society for Testing and Materials Committee on Temperature Measurement, Subcommittee SC.04, Thermocouples.

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

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

G. T. Furukawa, Member, ASTM E020, American Society for Testing and Materials Temperature Measurement Committee, Subcommittee SC.03, Resistance Thermometers; Subcommittee SC.04, Thermocouples; Secretary, Subcommittee SC.06, New Thermometers; and Member, Subcommittee SC.07, Fundamentals in Thermometry.

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

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

B. W. Mangum, Member, ASTM E020, American Society for Testing and Materials Temperature Measurement Committee, Subcommittee SC.03, Resistance Thermometers; Chairman, Subcommittee SC.06, New Thermometers; Member, Subcommittee SC.07, Fundamentals in Thermometry; Subcommittee SC.08, Medical Thermometry, Working Group GS.02, Fever Thermometers; Working Group WG.02C, Disposable Fever Thermometers; Working Group WG.03, Continuous Clinical Temperature Monitoring Systems; Working Group WG.04, Clinical Laboratory Temperature Measurement; and Member, Subcommittee SC.09, Advisory Committee.

B. W. Mangum, Member, NCCLS C002, National Committee for Clinical Laboratory Standards Area Committee on Clinical Chemistry, Subcommittee SC.01, Enzyme Assay Condition, Working Group WG.01, Temperature Measurement and Control; and Member, NCCLS C010, Area Committee on Instrumentation, Subcommittee SC.01, Temperature.

James F. Schooley, Member ANSI MC088, American National Standards Institute Committee on Calibration of Instruments.

James F. Schooley, Member, CIPM CCT, International Committee on Weights and Measures Consultative Committee on Thermometry; and Delegate, Subcommittee SC.01, Replacement of IPTS-68.

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

James F. Schooley, Program Chairman, The 6th Symposium on Temperature: Its Measurement and Control in Science and Industry.

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

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

Charles R. Tilford, Assistant Chairman, AVS C004, American Vacuum Society Standards Committee; and Chairman, Subcommittee SC.01, Gaging.

Charles R. Tilford, Member, BIPM C002, International Bureau of Weights and Measures Committee on Pressure Standards; Member, WG.01, Working Group on High Pressures; Chairman, WG.02, Working Group on Low Pressures; and Member, WG.03, Working Group on Barometric Pressures.

Jacquelyn A. Wise, Member, ASTM E020, American Society for Testing and Materials Temperature and Measurement Committee, Subcommittee, SC.01, Editorial and Nomenclature; and Secretary, Subcommittee SC.05, Liquid-in-Glass Thermometers and Hydrometers.

## Consulting and Advisory Centers

G. W. Burns, working in collaboration with H.P.R. Frederikse and P. K. Schenck of the NBS Center for Materials Science and with R. R. Dils and J. R. Whetstone of the NBS Center for Chemical Engineering, conducted a study of materials needed to solve instrumentation problems existing in various fossil energy technologies. The study was carried out at the request of the DoE Fossil Energy Program. A comprehensive report summarizing the findings of the study and giving recommendations for needed R&D programs was prepared for DoE by the NBS team and soon will be published as an NBSIR.

G. W. Burns, at the request and expense of the Owens-Corning Fiberglass Corporation, spent a day at the Technical Center of the Corporation in Granville, OH, and at a fiberglass manufacturing plant in Newark, OH, where he provided consultation on suitable thermometry to use for production. Comments and recommendations were offered regarding the selection, thermocouple thermometers for such applications.

Dr. Harvey Marshak was appointed a visiting Professor of nuclear and nuclear orientation physics at the Katholieke Universiteit, Leuven, Belgium, for a period of five months during 1981. His duties are to help them in their experimental program in the above fields and assist them in their low-temperature thermometry measurements.

LENGTH AND MASS MEASUREMENTS AND STANDARDS DIVISION

SUMMARY OF ACTIVITIES

FISCAL YEAR 1981

## I. OVERVIEW

Measurements and Standards Division (LMMSD) has
tain the U.S. primary standards, to transfer
secondary standards, and to improve the
and applied research.

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her national laboratories to
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libration services to other
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Consulting and Advisory Centers

G. W. Burns, working in collaboration with H.P.R. Frederikse and P
Schenck of the NBS Center for Materials Science and with R. R. D
J. R. Whetstone of the NBS Center for Chemical Engineering, c
study of materials needed to solve instrumentation problems
various fossil energy technologies. The study was carrie
request of the DoE Fossil Energy Program. A comprehens
izing the findings of the study and giving recommend
programs was prepared for DoE by the NBS team and
as an NBSIR.

G. W. Burns, at the request and expense of
Corporation, spent a day at the Technical
Granville, OH, and at a fiberglass manu
where he provided consultation on su
tion. Comments and recommendation
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Dr. Harvey Marshak was appo
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LENGTH AND MASS MEASUREMENTS AND STANDARDS DIVISION

SUMMARY OF ACTIVITIES

FISCAL YEAR 1981

# I. OVERVIEW

The Length and Mass Measurements and Standards Division (LMMSD) has the responsibility to maintain the U.S. primary standards, to transfer the U.S. primary standards to secondary standards, and to improve the primary standards through basic and applied research.

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

The Division has completed several long-term projects during the past year including: development of the Portable Laser Length Standard, modifications of the Voland balance which serves as the NBS Primary Kilogram Comparator, the Load Cell Mass Comparator, and the submersible balance for solid-object density comparisons. Significant progress has been made on the stabilization of the mercury laser and the certification of the silicon density standards for the Standard Reference Materials Program. Work this coming year will focus on completing these latter two projects, initiating international comparisons of the Kilogram and the new density standards, and on a major new project to design and construct an evacuable servo-controlled kilogram mass comparator.

# II. TECHNICAL ACTIVITIES

## Portable Laser Length Standard

The portable iodine stabilized helium-neon laser length standard developed in the Division has received an IR-100 award for being considered one of the 100 most significant products introduced in 1981. This award will provide significant impetus to the commercialization of this instrument by providing very high quality publicity. Frequency and Time Systems, Inc. (Beverly, MA), which has shown very strong interest in adding the portable laser length standard to its product line of quartz crystal and cesium oscillators, is encouraging organizations to place orders in the anticipation of manufacture and sale. The strong development effort which we have put into the intracavity iodine stabilized helium-neon laser has now concluded with the design and fabrication of a housing which provides personnel protection and graceful appearance. Some activity in evaluating the performance of the commercial version is anticipated, however, when the first models are built.

The design and construction of an external cell iodine stabilized helium-neon laser has been completed and initial measurements have been made, however, definitive statements regarding its performance are premature. At least an order of magnitude improvement in absolute resetability is anticipated as a consequence of deconvolution of the neon gain and iodine absorption mechanisms. The external cell system will become the LMMSD laboratory standard against which internal cell instruments can be compared.

## Stabilized Mercury Laser

The optically pumped mercury laser was stabilized to an iodine transition in an internal cell laser. This is the first time this stabilization has been reported and portends a system similar to the portable helium-neon length standard but at a higher level of performance. Significant data has been collected about the mercury spectrum (four suitable isotopes) and the iodine absorption spectrum (diatomic, two isotopes) in an effort to select the optimum combination. Several months of this study remain. During the course of this investigation four wave conjugate mixing was observed and is the first such observation reported for mercury. Although this is interesting from a scientific point of view, no metrological benefits are anticipated. While the four lamp close-coupled pump lamp configuration has worked reliably, other pump lamp configurations are being investigated in an effort to reduce complexity and size of the laser head while maintaining good performance. At the appropriate time, the frequency of this laser will be measured relative to the cesium oscillator at the Boulder laboratories.

## Primary Kilogram Comparator

A number of modifications have been made to the Voland balance so that it now achieves a routine standard deviation of 3-6 micrograms when intercomparing four stainless steel kilograms. In addition, two 500-g platinum-iridium (Pt-Ir) counterweights have been fabricated, which will allow us to intercompare Pt-Ir kilograms either with stainless steel or other Pt-Ir kilograms.

The balance performance would probably benefit from further modifications: new knives, air-tight enclosure, mechanically driven weight changer, and automatic readout. Each of these would be very costly of either personnel or resources. We believe, however, that the Voland balance in its present state will be adequate for our needs until the servo-controlled balance now under development becomes operational.

In the next year there are three projects which will make use of our primary comparator: 1) recalibration of U.S. prototype kilogram K-20 against international standards maintained at BIPM (last done in 1948); 2) recalibration of U.S. working standards N1 and N2; 3) participation next summer in a round robin between NBS, NRC (Canada) and BIPM to intercompare the same stainless steel and Pt-Ir kilograms.

## Servo-Controlled Kilogram Mass Comparator

A new project has been started which will focus on the theory and practice of servo-controlled, single pan, knife-edge mass comparators. The motivation for this endeavor is several fold. Modern servo technology combined with new modes of balance operation (constant load, static beam) portend unprecedented accuracy coupled with total computer control. This system will permit, for the first time, analytical studies on beam dynamics and allow balance optimization through a comparison of theory and performance. The balance will eventually be mounted in an evacuable enclosure to permit accurate measurements of air buoyancy effects without recourse to a semi-empirical equation-of-state for moist air. Errors in air buoyancy corrections presently dominate the uncertainty when platinum and stainless-steel kilograms are compared on the best balances. The program is in the planning stage although some optical equipment has been purchased for the angle interferometer which will measure the beam position. Initial studies will focus on servo elements, beam motor and position indicator, and on knife loading and geometry. Completion of this project is expected in three years.

## Load Cell Mass Comparator

The Division activities relating to development of the load cell mass comparator, its acceptance by the measurement community, and manufacture by an independent company are culminated with success in all areas. The need to continue this activity on any basis other than occasional consulting no longer exists.

The Office of Weights and Measures supported the Division's effort to complete a 50 pound instrument designed to tolerance test weights in the State laboratories. This device is to be loaned to several states to acquaint them with the advantages of the instrument. Texas was the first state to receive the mass comparator and is now performing weekly tests to determine its efficiency.

Extensive consulting with White Sands Missile Range Mass Laboratory has lead to their success in fabricating a load cell comparator with a range from 500 to 1500 pounds with a precision of 1 ppm. Their success besides being an independent confirmation (to be reported at the next ISA Conference) of the load cell mass comparator has made available for the White Sands Laboratory automatic data acquisition that was not possible with the mechanical balance employed by them.

This year three additional papers were prepared for publication; two dealing with the mechanics and electronics of the mass comparator and a third presented to the annual conference of the Institute for Nuclear Materials Management in San Francisco, CA. This latter paper described to the nuclear industry the advantages of incorporating the load cell mass comparator in their production weighing and safeguard programs.

A significant advance in the acceptance of the load cell mass comparator has been the decision of the Frazier Precision Instrument Company, an old line balance manufacturer, to manufacture the mass comparator in several ranges from 50 pounds to 10,000 pounds. Personnel of the Division have given the Frazier engineers assistance on request to ensure the transfer of technology from NBS to the private sector.

Submersible Balance and Density SRM

The project to deliver 70 solid-object density standards to the Office of Standard Reference Materials (OSRM) is nearing completion. The fabrication of all 70 artifacts, fashioned from single-crystal silicon, is now finished. It only remains to certify the density of these objects against our working standards. The latter endeavor will be completed very early in FY'82 thanks to an innovative submersible balance, developed within the Division, which allows density certification to one part per million in a fraction of the time required by traditional techniques. Development and testing of the high-precision submersible balance is complete. The rapid measurement capabilities of this new balance become extremely valuable given the number of objects to be certified for the OSRM. The submersible balance has also proven useful for 1) screening a large number of materials for use in experiments where density is an important factor, such as the measurement of the gravitational constant being conducted elsewhere in the Center; and 2) determining the volume of working mass standards such as those of Sandia Laboratories in Albuquerque, NM. (The altitude of this laboratory is high enough that buoyancy corrections in air weighings are significantly different from those of laboratories near sea level, hence their interest in accurate knowledge of the volumes of their standards).

The unique feature of the SRM is that it will provide the purchaser with a highly homogeneous object whose density is extremely well known, being directly traceable to base units of mass and length. In practice, this means we must compare hydrostatically the newly fabricated artifacts against our existing working standards of density. The completion of this project will enable the public to obtain density reference standards which have a higher degree of permanance and stability than distilled water, the usual density reference. Another attractive feature is that purchasers can further shape and etch the SRM to fit their experimental needs without changing the certified density.

The expertise developed in this work will be useful in projected international intercomparisons of solid density standards. These will occur as a part of NBS participation in the activities of a newly organized working group of the Consultative Committee for Mass and Related Quantities.

## INVITED TALKS

### Length & Mass Measurements & Standards Division (523)

H. P. Layer, "The Laser Length Standard: The Definition of the Meter," January 7, 1981, National Association for the Advancement of Science, Toronto, Canada.

H. P. Layer, "The Length Standard and Fundamental Constants," January 20, 1981, Yale University Physics Department, New Haven, Connecticut.

H. P. Layer, "The Length Standard and Fundamental Constants," January 21, 1981, Frequency and Time Systems, Boston, Massachusetts.

## PUBLICATIONS

### Length & Mass Measurements & Standards Division (523)

In Print:

R. M. Schoonover, "A simple gravimetric method to determine barometer corrections," J. Res. Nat. Bur. Stand. 85(5), 341-345, Sept-Oct 1980.

Howard Layer, "A portable iodine stabilized helium-neon laser," IEEE Trans. on Instrumentation and Measurements, IM-29, No. 4, 358-361, December 1980.

Fielding Ogburn, Randall M. Schoonover, and Christian E. Johnson, "Density of autocatalytic nickel-phosphorus deposits," Plating and Surface Finishing, p. 45, March 1981.

H. P. Layer, W. R. C. Rowley, and B. R. Marx, National Physical Laboratory-National Bureau of Standards iodine-stabilized helium-neon laser intercomparison," Opt. Lett. 6(4), 188-190, April 1980.

R. Schoonover and Frank Jones, "Air buoyancy correction in high-accuracy weighing," Anal. Chem. 53, 900-902, May 1981.

A. L. Cummings, H. P. Layer and R. J. Hocken, "Lasers and Analytical Polarimetry," Chapter 15 in Lasers in Chemical Analysis, ed. by Gary M. Hieftje, John C. Travis, and Fred E. Blytle, The Humana Press, 1981. p 291-302.

In Press, in Review, or Nearing Completion:

R. D. Cutkosky and R. S. Davis, "Simple control circuit for temperature regulation and other bridge applications," Rev. Sci. Instrum. (to be published in the September 1981 issue).

Marvin E. Cage and Richard S. Davis, "An analysis of read-out perturbations seen on an analytical balance with a swinging pan," (accepted for publication in NBS. J. Res.).

Randall Schoonover, "A 30 Kg capacity high precision load cell mass comparator," (accepted for publication in NBS J. Res.).

S. Suda, P. Pontius, and R. Schoonover, "Improved mass measurement accuracy using the PNB load cell scale," Proc. of Institute of Nuclear Materials Management 22nd Annual Meeting in San Francisco, CA, July 13-17, 1981.

V. E. Bower, R. S. Davis, T. J. Murphy, P. J. Paulsen, J. W. Gramlich, and L. J. Powell, "Recalculation of the Faraday Constant due to a new value for the atomic weight of silver," (in preparation).

## SEMINARS ORGANIZED

### Length & Mass Measurements & Standards Division (523)

R. S. Davis, an informal meeting of mass metrologists held during the PMFC-II Conference, June 9, 1981.

R. M. Schoonover, George Washington University Engineering Seminar, "Operation and Management of Standards Laboratories."

R. M. Schoonover, taught a two-week course for the Office of Weights and Measures on Basic Metrology. This course covered in total, lab management, mass calibration, volumetric, length calibrations and associated statistics.

## 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.

## TRIPS SPONSORED BY OTHERS

### Length & Mass Measurements & Standards Division (523)

H. P. Layer — January 6-8, 1981 - Toronto, Canada
Presented an invited talk to the American Association of Advanced Science to help disseminate basic standards to the scientific community and to meet and confer with scientists with matters of Bureau interest.
Sponsor: AAAS

H. P. Layer — January 18-20, 1981 - New Haven, Connecticut
Presented an invited talk at Yale University and calibrated a Rydberg constant experiment.
Sponsor: Yale University

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# TIME AND FREQUENCY DIVISION

## SUMMARY OF ACTIVITIES

## FISCAL YEAR 1981

## I. Overview

The Time and Frequency Division provides the basic standards for the country in the areas of frequency and time interval. These standards must be coordinated both nationally and internationally in order to ensure compatibility of all measurements. By international agreement, the definition of the unit of time, the second, is in terms of the cesium beam frequency standard. Currently three countries (U.S., Canada, and West Germany) have primary cesium beam frequency standards of sufficient quality for inclusion into the official, internationally cordinated time scales. The U.S. standard is provided by the Division.

To ensure the Division's effectiveness, the Division maintains primary cesium beam frequency standards; undertakes research and development on new and improved standards and measurement methods; extends accurate frequency measurements into the visible region; actively compares the NBS standards and time scales with others, both nationally and internationally; and provides access to the coordinated standards via various dissemination services. The skills and knowledge developed in this process are applied to related problems of national interest and made available to other government agencies.

While time and frequency can be measured with the smallest percentage error of any physical quantity, even greater performance than currently available is demanded of these measurements. Precise and accurate time and frequency signals are essential for such things as television, electric power system control, navigation, communication, and the operation of the telephone system. Because the potential for even more accurate and precise standards is so great, many laboratories seek improved performance of oscillators and clocks. One significant example of this is in the development of the Global Positioning System (GPS) by the military. Current design goals for GPS require routine performance of devices at or exceeding the present state-of-the-art in the most sophisticated laboratories. Also, standards laboratories of other nations are perfecting primary standards equal to or better than the present NBS standard, NBS-6.

As a result, there is significant pressure on the Division not only to remain current, but to provide new developments and measurement methods in the area of time and frequency. Over the past several years the Division has demonstrated the feasibility of redefining the unit of length, the meter, in terms of the unit of time. In effect, the meter could be defined as the distance traversed by a light wave in some specified fraction of a second. The result would be both an improvement in the standard of length and a conceptual refinement of the International System (S.I.) of units. Currently, the Division has committed itself to the performance of a measurement which is crucial to the practical realization of the redefinition of the meter. This measurement, which is the precise determination of the frequency of a particular optical transition in iodine relative to the NBS primary frequency standard, will be both the most accurate optical frequency ever measured and the highest frequency ever measured directly. It is scheduled for completion in FY 82.

The Division has begun to design and plan for the next generation of primary frequency standard, NBS-7. The present standard, NBS-6, has served well at an accuracy of about 8 parts in ten to the 14th, but laboratories of other nations specify finer tolerances, newer systems demand ever increasing accuracies, and the means of building a better standard are now known. The new standard will still be based on cesium, but new techniques of state selection and detection, developed by the Division, will allow improvement by a factor of about ten in accuracy and stability over NBS-6. The budgeting process will be initiated in FY 82 and research on techniques to improve primary standards will continue. The final design and construction of NBS-7 will begin in FY 84 with the availability of the funds. Research on other more advanced standards concepts (such as stored, cooled ions) will continue.

A radio navigation system, Loran-C, currently provides the means of comparing standards and time scales internationally. Unfortunately, the accuracy attainable with Loran-C is a severe limitation and more accurate means of comparison are badly needed. Satellite systems provide the best current hope for improvement and have demonstrated accuracies of time transfer about a hundred times better than possible with Loran-C. What is still needed is an operational system performing at these higher accuracies. One significant, possible system is GPS. The Division has devised and tested a GPS receiver based on common-mode reception of GPS signals. This system allows time comparisons with a precision of a few nanoseconds and frequency comparisons to a few parts in ten to the 15th in a period of several weeks. Plans are under way to make comparisons of frequency and time using these GPS receivers with a few key national and international laboratories. Since the future of GPS is uncertain, other options are also being studied.

Various services provide general access to the NBS standards of frequency and time. Radio stations WWV, Ft. Collins, Colo., and WWVH, Kauai, Hawaii, provide continuous broadcasts of standard time and frequency in the short-wave bands. These broadcasts are probably the primary references for standard time at modest accuracies (greater than a millisecond) for most of the U.S. and the surrounding oceans. Somewhat better accuracies can be obtained from the broadcasts of WWVB, Ft. Collins, Colo., and from the satellite broadcasts from NOAA's GOES satellites. The Division provides the time signals for the GOES broadcasts and these services are receiving increased attention, primarily by electric power companies.

Approximately one quarter of the Division's funding support comes from other government agencies. The Division has been able to foster contracts which both augment our efforts on the primary mission and provide useful services and data to the funding agencies. These other agencies have been interested in supporting such efforts as the development of clocks with improved stability (e.g., passive hydrogen masers), and research on future frequency standards options (e.g., stored ions).

## II. Technical Activities

### 1. Primary Standards

During the last several years the Division has pursued a specific strategy which can be summarized as follows:

A. Primary Group effort on research and development of new standards options.

B. Maintain "adequate" primary frequency calibrations by evaluating NBS-6 about once per year.

The rationale for this strategy has been that the accuracy attainable with NBS-6 was adequate for commercially available clocks and oscillators. Operating NBS-6 as a "standard clock", as other laboratories have done, provides little improvement at the cost of much effort which could more profitably be directed toward advanced research on improved primary frequency standards.

More recently, two new directions have been added to the strategy. These are:

C. Construct a new time scale hardware and control system and develop a new time scale algorithm.

D. Develop specific plans to build the next generation of primary frequency standard, NBS-7.

The old time scale control system was based on 1967-vintage computer systems and time measurement hardware with accuracies of about one nanosecond. The system severely limited the abililty to evaluate new devices (such as the passive hydrogen maser), provided no opportunity to increase the number of clocks contributing to the time scale, and provided no opportunity to develop and test new time scale algorithms with real clocks. The new system includes a totally new computer (PDP 11/70) for control and newly designed measurement hardware (developed by the Group) which is capable of sub-picosecond resolution and time stability of a few picoseconds over periods of months. This is an improvement of nearly two orders of magnitude over the previous state-of-the-art. Most of the hardware now exists and has been tested and verified. The new computer now computes the official time scale (using essentially the old algorithm adapted to the new computer), and both hardware and software are being assembled to make automatic clock comparisons with the new hardware. Final assembly and testing should be completed in the next few months.

A new time scale algorithm (based on Kalman filters) is under development. We have been fortunate in interesting some people in the Statistical Engineering Division in the problem. This turns out to be a most fruitful collaboration and some significant progress has been made on the problems of adaptive parameter estimation. While the implementation of a Kalman filter algorithm is reasonably straightforward, the estimation of the model parameters for the filter is more subtle. A complete time scale algorithm should be under test by the end of FY 82 and a paper prepared for the Second International Symposium on Time Scale Algorithms, hosted by the Division next June.

We have begun the process of acquiring funds to design and know that NBS-7 will be a cesium beam device and will probably employ optical pumping techniques for state selection and detection. The presently stated goal is to build a device with an absolute accuracy of one part in ten to the 14th, and a frequency stability of about (3 E-13/root-tau) improving out to averaging times of at least one day. Optical state selection can increase signal-to-noise by pumping all atoms into the desired state. This should result in a factor of 16 enhancement in the usable beam and greatly reduce the background as compared to present cesium beam designs. Moreover, the lack of population in the other hyperfine sublevels should permit a study of Majorana transitions. These transitions occur between the magnetic state selection region and the Ramsey cavity region in current cesium beam design and are a concern in the accuracy of cesium standards. Optical pumping and laser fluorescence detection of the cesium atoms will permit the use of smaller, more symmetric atomic beams, which will decrease sensitivity of the standard to distributed phase shifts across the openings of the cavity. We have demonstrated the necessary selection rules for this process and are testing laser diodes for a practical implementation. We are also developing a more efficient, high-flux oven and investigating the electronics required for an adequate servo for the standard.

NBS-7 will have to be a totally new device, separate from NBS-6. During the design and construction phases of NBS-7, we will continue to operate NBS-6 in its present mode of about one complete evaluation per year. The intent is to submit a budget initiative for FY 1984. To meet that schedule, the paperwork is due this coming Spring.

Passive hydrogen masers have been perfected to the point where they now demonstrate a frequency stability of a few parts in ten to the 15th for averaging times of a few days, which is comparable to the entire present time scale. This is at least ten times better than active masers. One passive maser has been incorporated into the NBS time scale and data is accumulating.

In addition to work specifically directed toward NBS-7, work has continued on concepts for more advanced frequency standards (i.e., for a generation of standards following NBS-7). 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. The result is the confinement of ions which are nearly at rest (i.e., at a temperature of only a few millikelvin). Magnetic hyperfine linewidths of a few millihertz (the linewidth of NBS-6 is 30 Hz) have been observed with the system. Furthermore, the effects of the confinement on the ions is both very small and calculable, so that potential use with primary frequency standards operation is good.

Cooled ions have potential stability and accuracy advantages over cesium beams. 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 1.0 E-12 to 1.0 E-16 divided by root-tau, 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 the order of 1.0 E-14 to 1.0 E-16 divided by root-tau. Work on more stable laser flywheel oscillators is also being pursued in conjunction with the stored ion effort. Absolute accuracies of 1.0 E-15 and frequency stability in the low 1.0 E-16 range for days to weeks are anticipated (again limited by the local oscillator, i.e., the laser). 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 10 years.

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 the 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-half 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.

2. Coordination

Time and frequency are quantities which must be actively and closely coordinated both nationally and internationally. This is currently accomplished by monitoring signals of the Loran-C navigation system and communicating the results to the International Time Bureau (BIH), which acts as the central "clearing-house" for time and frequency data. In turn, the BIH constructs the official time scales TAI and UTC (International Atomic Time and Coordinated Universal Time, respectively). All standard time in the world is referenced to UTC.

The NBS contributes to the formation of TAI and UTC by supplying data on accurate frequency relative to NBS-6 and by supplying data on the stable clocks of the NBS Time Scale. The accuracy and precision of the data are degraded by the comparison link, Loran-C, sufficiently that even after a year's average, uncertainties of nearly one part in ten to the 13th remain. This is comparable to the absolute accuracy of NBS-6. Because of the variability in the comparison links, meaningful comparisons of the world's primary frequency standards are severely limited and comparison results are very unsatisfying.

In recent years, numerous laboratories (including NBS) have demonstrated that improved accuracy and precision of comparison can be obtained from satellite systems. Not only can these satellite systems provide improved time comparisons, they need accurate and stable frequency and time references. They provide both a means of improved comparison and a demand for better and more accurate clocks.

In addition to the routine monitoring of Loran-C, the Division has a program devoted to the development of a time comparison technique based on the use of the Global Positioning System (GPS), which is under development by the Department of Defense. The Time and Frequency Division devised a technique of using GPS satellites in common view of two time laboratories for extremely precise time transfer. We have developed and are now in the testing phase of a GPS receiver which has demonstrated time transfer precisions in the nanosecond range and frequency measurement consistencies a hundred fold better than possible with Loran-C. These tests have been carried out in cooperation with the U.S. Naval Observatory (USNO). Other governmental agencies have shown significant interest in these GPS receivers and have helped fund the development. Because of uncertainties in the future of the entire GPS system, the Division continues to investigate other satellite options also.

3. Laser Frequency Metrology

The current definition of the unit of length, the meter, is in terms of the orange-red line of the krypton lamp. This standard is practically limited at about four parts in ten to the 10th. The possibility exists (and has been demonstrated by the Division) to measure the frequency of a very stable and reproducible laser in the optical region and effectively transfer the accuracy of the cesium beam frequency standard to a new length standard. In effect, one defines the speed of light in this process. This possibility has been recognized for some time and the organizations of the Treaty of the Meter are expected to take specific action in the summer of 1982 to redefine the meter. The Consultative Committee for the Definition of the Meter (CCDM) is a technical advisory committee to the International Committee of Weights and Measures (CIPM). At its meeting next June, the CCDM is expected to recommend to the CIPM that the meter be redefined as the distance traversed by a light wave in a specified fraction of a second.

In preparation for this CCDM meeting the Division has undertaken the accurate measurement of the 520 THz line of iodine relative to the cesium primary frequency standard. This measurement involves the construction of a "chain" of lasers from the far infrared to the visible region. Each laser's frequency is measured in terms of a lower frequency laser or the primary frequency standard at the beginning of the chain. Knowing the exact frequency of the 520 THz line of iodine establishes a link between optical wavelength standards and the primary frequency standard.

Current efforts involve the perfection of a color-center laser operating in the infrared region. With the completion of this task, all elements of the chain will have been proven. The remaining task will be the operation of the complete chain and the exact determination of the iodine frequency.

For practical purposes, there is still significant value in determining a few key "benchmark" frequencies in the infrared region relative to cesium. Some work continues in this area.

The Division's expertise in lasers and atomic and molecular physics has been applied to related problems also. Laser Magnetic Resonance (LMR) spectroscopy was initiated in a 1966 experiment at NBS. During the last year, LMR has proceeded with the operation of a new spectrometer with a larger magnet and a more homogeneous field. This new spectrometer has demonstrated about a five-fold improvement in sensitivity. The LMR program continues to be a cooperative effort with NOAA and largely funded by other agencies. Most recent studies include spectra of oxygen molecules with mixed isotopes. During the next few months, we plan completion of the analysis of the CH frequencies for radio astronomy and completion of spectra and identification of CH2.

Another major area of frequency application is the laser geodimeter. This instrument is an outgrowth of previous work on laser strainmeters. In the early 1970's, a 30-meter interferometer was constructed in the Poor Man Mine in Boulder Canyon as part of the measurement of the velocity of light. During the past year, the geodimeter has undergone testing over short ranges, mainly within the lab. The geodimeter is a three-frequency device designed to allow the calculation of the integrated water vapor content along a path of up to 50 kilometers. The water vapor content is the primary limiting effect on the determination of the index of refraction of the air along the path. Knowing the integrated correction allows one to determine real variations of the path length rather than variations in the water vapor content. This device has potential application in forecasting earthquakes. Also significant interest has developed in a device which is capable of determining water vapor content along a path.

During the present Fiscal Year (FY82) the geodimeter will undergo more extensive field tests. Initial tests will be done locally and later the geodimeter will be tested in earthquake-active areas in California. Much of this work has been supported with other agency funds.

An outgrowth of our precision measurement work and our interests in geophysics is the work on tiltmeters, which is almost entirely funded by other agencies. A group of very accurate tiltmeters has been built and installed in wells at a site near the Boulder Labs. Each tiltmeter is in a 100 foot deep well and is equipped with its own data telemetering system. Data has been accumulating for the past several months and verifies both the high sensitivity of the tiltmeters and the very high consistency of the tiltmeters between each other. The next phase will be to install the tiltmeters in a seismically active area.

4. Time and Frequency Services

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, WWVB; 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.

The broadcast services of WWV, WWVH, and WWVB operate with downtimes of less than 0.1%. These services continue to be a major source of time and frequency information in the Western Hemisphere.

During the past few years, a modernization program has been under way at WWVB. Nearly 20 years ago, the WWVB transmitters were constructed from surplus military transmitters and the WWVB antennas and drivers were installed at Ft. Collins. A couple years ago equipment funds were made available to renovate WWVB. This has just been completed and the WWVB system should be good for another ten to fifteen years.

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 four years. This time code was the first routine time broadcast from a satellite, but because it was established mainly to serve the NOAA data bouy system, the transmission frequency is in the satellite meteorology band, not in the 400 MHz time and frequency allocated band. Two manufacturers currently market GOES time code receivers. The more sophisticated version, with automatic path delay compensation, is priced at $3500 each. The second supplier markets several models of a simpler version for $2200. Nearly a thousand receivers now exist and are used by the electric power industry, the military, scientific applications and more.

Increasing interest is evident in adding a compatible time code to the European METEOSAT and the Japanese GMS components of the overall meteorological satellite system, of which GOES is the U.S. component. Such an extension to other satellites is being requested by European and Japanese timekeeping organizations and will not directly involve NBS, except possibly in an informal consulting role.

INVITED TALKS

Time and Frequency Division (524)

K. M. Evenson, "Far Infrared Laser Magnetic Resonance," Non Linear Laser Spectroscopy Conference. Joint Japan-U.S. participation, Kauai, Hawaii, September 10, 1980.

D. J. Wineland, "Atoms at Rest in Space; The Spectroscopists Ideal," Physics Department, University of North Carolina, January 25, 1981.

D. J. Wineland, "Laser Cooling of Stored Ions," American Physical Society and American Association of Physics Teachers, New York, N.Y., January 28, 1981.

D. W. Allan, "Some Methods of Maintaining and/or Generating Time and Frequency at Arbitrary Points on the Surface of the Earth," International Symposium on Time and Frequency, National Physical Laboratory, New Delhi, India, February 10, 1981.

R. E. Beehler, "Time/Frequency Dissemination Services from NBS and Some Alternatives for Future Improvements," International Symposium on Time and Frequency National Physical Laboratory, New Delhi, India, February 11, 1981.

L. L. Lewis, "Use of Diode Lasers in Cesium Frequency Standards," Electro-Optics Group McDonnell-Douglas Aircraft Corp. St. Louis, MO., February 19, 1981.

D. J. Wineland, "Cesium and Rubidum Atomic Clocks," Seminar on: Frequency Standards Measurement and Usage, Laboratoire de Physique et Metrologie des Oscillateurs, Besancon, France, March 23, 1981.

D. J. Wineland, "Ion Storage and the Future of Atomic Clocks," Seminar on: Frequency Standards Measurement and Usage, Laboratoire de Physique et Metrologie des Oscillateurs, Besancon, France, March 24, 1981.

F. R. Petersen, "Laser Frequency Measurements and Molecular Spectroscopy," NBS - Gaithersburg, April 22, 1981.

F. R. Petersen, "Frequency Measurements in the Visible: Are We Close to a Unified Time and Length Standard?," American Physical Society, Baltimore, Maryland, April 23, 1981.

K. M. Evenson, "Laser Magnetic Resonance of Free Radicals Important in Radio Astronomy," MIT, Boston, MA, April 28, 1981.

K. M. Evenson, "Laser Magnetic Resonance of Free Radicals Important in Radio Astronomy," Georgia Tech, Atalanta, GA, April 29, 1981.

K. M. Evenson, "Laser Magnetic Resonance of Free Radicals Important in Radio Astronomy," Physics Department, Colorado State University, Fort Collins, CO, May 5, 1981.

K. M. Evenson, "Laser Magnetic Resonance of Free Radicals Important in Radio Astronomy," Physics Department, University of Colorado, Boulder, CO, May 8, 1981.

K. M. Evenson, "Laser Magnetic Resonance of Free Radicals Important in Radio Astronomy," Physics Bldg., University of Arizona, Tucson, AZ, May 11, 1981.

D. A. Howe, "Properties of Signal Sources," 35th Annual Symposium on Frequency Control, Marriott Hotel, Philadelphia, PA, May 27, 1981

D. W. Allan, "Construction and Performance Characteristics of a Prototype NBS/GPS Receiver," 35th Annual Symposium on Frequency Control, Marriott Hotel, Philadelphia, PA, May 28, 1981.

L. L. Lewis, "Optical Pumping by Lasers in Atomic Frequency Standards," 35th Annual Symposium on Frequency Control, Marriott Hotel, Philadelphia, PA, May 28, 1981.

D. J. Wineland, "Proposed Stored Ion Primary Frequency and Time Standard," 35th Annual Symposium on Frequency Control, Marriott Hotel, Philadelphia, PA May 28, 1981.

D. W. Allan, "A Modified 'Allan Variance' with Increased Oscillator Characterization," 35th Annual Symposium on Frequency Control, Marriott Hotel, Philadelphia, PA, May 29, 1981.

W. M. Itano, "Progress Toward a Stored Ion Frequency Standard at the National Bureau of Standards," Second International Conference on Precision Measurements and Fundamental Constants, Holiday Inn, Bethesda, MD, June 8, 1981.

D. J. Wineland, "Spectroscopy of Stored Ions," Second International Conference on Precision Measurements and Fundamental Constants, Holiday Inn, Bethesda, MD, June 8, 1981.

L. L. Lewis, "Prospects for Cesium Primary Standards at the National Bureau of Standards," Second International Conference on Precision Measurement and Fundamental Constants, Holiday Inn, Bethesda, MD, June 8, 1981.

D. J. Wineland, "Ion Storage and Optically Pumped Standards," XXth General Assembly of the International Union of Radio Science, Hyatt Regency Hotel, Washington, DC, August 12, 1981.

R. E. Beehler, "General Review of Time Coordination and Dissemination by Satellite," XXth General Assembly of the International Union of Radio Science, Hyatt Regency Hotel, Washington, DC, August 12, 1981.

F. L. Walls, "Timekeeping with Passive Hydrogen Masers," XXth General Assembly of the International Union of Radio Science URSI, Washington, DC., August 12, 1981.

## 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.

D. W. Allan, 1981 PTTI Program Committee.

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

J. A. Barnes, Delegate USRI.

J. A. Barnes, Professor Adjunct, University of Denver.

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."

K. M. Evenson, URSI Commission D.

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

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.

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

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

## PUBLICATIONS

### Time and Frequency Division (524)

(R. Decher), D. W. Allan, (C. O. Alley, R. F. C. Vessot, and G. M. R. Winkler), A Space System for High-Accuracy Global Time and Frequency Comparison, Proc. 12th Annual PTTI Applications and Planning Meeting NASA Publication 2175, 99 (1980).

R. L. Barger, Simple Interferometric Technique for Alignment of Segmented Retroreflectors, Appl. Opt. 19, 2088 (1980).

J. A. Barnes, H. H. Sargent III, and P. V. Tryon, Sunspot Cycle Simulation Using Random Noise, Proc. Conf. Ancient Sun, 159 (1980).

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K. M. Evenson, (R. J. Saykally), D. A. Jennings, (R. F. Curl, Jr., and J. M. Brown), Far Infrared Laser Magnetic Resonance, Chemical and Biochemical Applications of Lasers 5, 95-138 (1980).

(Richard J. Saykally, Karen G. Lubic), and Kenneth M. Evenson, Structures of Molecular Ions from Laser Magnetic Resonance Spectroscopy, Proc. NATO Advanced Study Institute on Structures of Molecular Ions, Kos, Greece (1980).

Wayne M. Itano, D. J. Wineland, R. E. Drullinger, and J. C. Bergquist, High-Resolution RF Spectroscopy of Laser-Cooled $^{25}Mg^{+}$ Ions, Proc. International Conf. on Atomic Physics (1980).

L. L. Lewis, D. A. Howe, S. R. Stein, C. Manney, M. Mohler, J. C. Bergquist, D. J. Wineland, and F. L. Walls, Experiments to Reduce Cavity Phase Shift Errors in the Cs Beam Tube, Proc. Conf. of Precision Electromagnetic Measurements (CPEM) (1980).

A. Risley, S. Jarvis, Jr., and (J. Vanier), The Dependence of Frequency upon Microwave Power of Wall-Coated and Buffer-Gas-Filled Gas Cell $RB^{87}$ Frequency Standards, J. Appl. Phys. 51, 4571 (1980).

D. J. Wineland, J. C. Bergquist, Wayne M. Itano, and R. E. Drullinger, Optical Pumping and Double Resonance Experiments on Laser Cooled Ions, Proc. IEEE International Quantum Electronics Conf. (IQEC) (1980).

David W. Allan, Some Methods of Maintaining and/or Generating Time and Frequency at Arbitrary Points on the Surface of the Earth, Proc. International Symposium on Time and Frequency, New Delhi, India (1981).

NOTE: Names in parentheses ( ) are non-NBS authors.

David W. Allan and James A. Barnes, A Modified "Allan Variance" with Increased Oscillator Characterization Ability, Proc. 35th Annual Symposium on Frequency Control (SFC) (1981).

R. L. Barger, Influence of Second-Order Doppler Effect on Optical Ramsey Fringe Profiles, Opt. Lett. 6, 145 (1981).

R. E. Beehler, Time/Frequency Services of the U.S. National Bureau of Standards and Some Alternatives for Future Improvement, Proc. International Symposium on Time and Frequency, New Delhi, India (1981).

Dick D. Davis, Marc Weiss, Alvin Clements, and D. W. Allan, Construction and Performance Characteristics of a Prototype NBS/GPS Receiver, Proc. 35th Annual Symposium on Frequency Control (SFC) (1981).

(J. M. Brown, C. M. L. Kerr, F. D. Wayne), K. M. Evenson, and (H. E. Radford), The Far Infrared Laser Magnetic Resonance Spectrum of the OH Radical, J. Mol. Spectrosc. 86, 544 (1981).

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Bokuji Komiyama, Quartz Crystal Oscillator at Cryogenic Temperature, Proc. 35th Annual Symposium on Frequency Control (SFC) (1981).

(J. C. Harrison), J. Levine, and (C. M. Meertens), Design of a Deep Borehole Tiltmeter, Proc. 9th International Symposium on Earths Tides (1981).

J. Levine, (J. C. Harrison, and C. M. Meertens), Performance of a Deep Borehole Tiltmeter, Proc. 9th International Sypmposium on Earth Tides (1981).

(J. H. Hollister, G. R. Apperson), L. L. Lewis, (T. P. Emmons, T. G. Vold, and E. N. Fortson), Measurement of Parity Nonconservation in Atomic Bismuth, Phys. Rev. Lett. 46, 643 (1981).

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(E. C. C. Vasconcellos, A. Scalabrin), F. R. Petersen, and K. M. Evenson, New FIR Laser Lines and Frequency Measurements in $CD_3OD$, Int. J. Infrared and Millimeter Waves 2, 533 (1981).

(Robin S. McDowell, Chris W. Patterson, Norris G. Nereson), F. R. Petersen, and J. S. Wells, $CO_4$ Laser Coincidences with $\nu_3$ of $SiF_4$ near 9.7 μm, Opt. Lett. 6, 1981.

Earl W. Smith, Absorption and Dispersion in the $O_4$ Microwave Spectrum at Atmospheric Pressures, J. Chem. Phys. 74, 6658 (1981).

Earl W. Smith, An Analysis of Markovian Model Microfield Methods for Stark Broadening, J. Quant. Spectrosc. Radiat. Transfer 26, 229 (1981).

F. L. Walls and D. A. Howe, Precision Timekeeping Using a Small Passive Hydrogen Maser, Proc. 12th Annual PTTI (1981).

J. S. Wells, F. R. Petersen, (A. G. Maki, and D. J. Sukle), Heterodyne Frequency Measurements on the 11.6 μm Band of OCS: New Frequency/Wavelength Calibration Tables for 11.6 and 5.8 μm OCS Bands, Appl. Opt. 20, 1676 (1981)

David J. Wineland and Wayne M. Itano, Spectroscopy of a Single $Mg^+$ Ion, Phys. Lett. 82A, 75 (1981).

D. J. Wineland, Future Atomic Frequency and Time Standards, Proc. Frequency Standards Measurement and Usage Seminar (1981).

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D. J. Wineland, Wayne M. Itano, J. C. Bergquist, and F. L. Walls, Proposed Stored $^{201}Hg^{+}$ Frequency Standards, Proc. 35th Annual Symposium on Frquency Control (SFC) (1981).

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## SEMINARS

### Time and Frequency Division (524)

Time and Frequency Users' Seminar, Boulder, CO, August 26-27, 1981

Seminar on Properties of Signal Sources, US Army ERADCOM, 35th Annual Symposium on Frequency Control, Phildadelphia, PA, May 27, 1981.

## SPECIAL REPORTS

Final Report - NBS Contract NB80RAA02404, "Relativistic Kepler Problem and Construction of A Local Inertial Frame," Neil Ashby, Principal Investigator, September 1980.

CCIR Report - 23 March 1981, "Inclusion of Relativistic Effects in International Time Comparisons, David W. Allan, Contributor.

Final Report - U.S. Army Proposal Number DRXRO-PP-L-16899-P, "A Study of Clustering in Water Vapor at Ultraviolet Wavelengths," Jerry C. Wyss, R. E. Drullinger, E. W. Smith, and J. Cooper, Investigators. Submitted to U.S. Army Research Office, 10 April 1981.

## CONSULTING AND ADVISORY PARTICIPATION

### Time and Frequency Division (524)

D. W. Allan consulting with Air Force Space Division.

D. W. Allan consulting with Jet Propulsion Laboratory.

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

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

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

G. Kamas consulting with Rome Air Development Command.

L. L. Lewis consulting with GPS Steering Committee, Air Force Space Division.

F. L. Walls consulting with Air Force Space Division.

F. L. Walls consulting with Jet Propulsion Laboratory.

F. L. Walls consulting with Naval Research Laboratory.

F. L. Walls consulting with Rome Air Development Command.

## TRIPS SPONSORED BY OTHERS

Time and Frequency Division (524)

| | |
|---|---|
| D. W. Allan | February 5-20, 1981 - New Delhi, India. Attended and gave invited paper at the International Symposium on Time and Frequency. Also served as consultant for India and underdeveloped countries in regard to time and frequency matters.<br><br>Sponsor: National Physical Laboratory |
| F. R. Petersen | February 21-28, 1981 - Trondheim, Norway. Presented invited lectures and consulted with Norwegian Defense Research Establishment and at University of Trondheim on laser frequency measurements with MIM diodes.<br><br>Sponsor: Advisory Group for Aerospace Research and Development, NATO |
| D. J. Wineland | March 22-28, 1981 - Besancon, France. Attended Seminar "Frequency Standards, Measurement and Usage" and presented two invited papers, "Cs and Rb Atomic Clocks: and "Ion Storage and the Future of Atomic Clocks."<br><br>Sponsor: Centre National de la Recherche. |
| K. M. Evenson | April 27-30, 1981 - Boston, MA and Atlanta, GA. Presented invited talks at Massachusetts Institute of Technology and Georgia Tech entited "Laser Magnetic Resonance of Free Radicals Important in Radio Astronomy."<br><br>Sponsor: MIT and Georgia Tech.<br><br>May 10-12,1981 - Tucson, Arizona. Presented invited talk at University of Arizona entitled "Laser Magnetic Resonance of Free Radicals Important in Radio Astonomy."<br><br>Sponsor: University of Arizona. |

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|---|---|
| R. E. Drullinger | May 15, 1980 - May 16, 1981 - Munich, West Germany. Spent one year at Max Planck University to further develop the technique of using spectral shifts in electronic transitions to study small clusters.<br><br>Sponsor: Max Planck University |
| D. J. Wineland | July 5-11, 1981 - Wolfboro, New Hampshire. Presented invited talk at Gordon Conference on Atomic Physics.<br><br>Sponsor: Brewster Academy. |

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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 new energy sources; to the collection and evaluation of scientific data; and to the education of scientists. The need for JILA to be dynamic in its focus and programs was stated in the Amendment to the Memorandum of Understanding signed in 1976 by NBS and CU. The QPD is one of the divisions in NBS with heaviest emphasis on basic research and the advancement of measurement science from a fundamental point of view, and the ability to carry this out is emphatically enhanced and leveraged by the location of the QPD on the CU campus and participation of doctoral and postdoctoral students.

The Quantum Physics Division currently has substantial research programs in five general areas, to be discussed in more detail later:

1. Fundamental and precision measurements.

2. Geophysical measurement methods.

3. Astrophysical measurement.

4. Atomic and molecular physics and interactions.

5. Chemical physics.

Currently, there are 162 total personnel 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.

JILA STAFFING

1981-82

(162 Total)

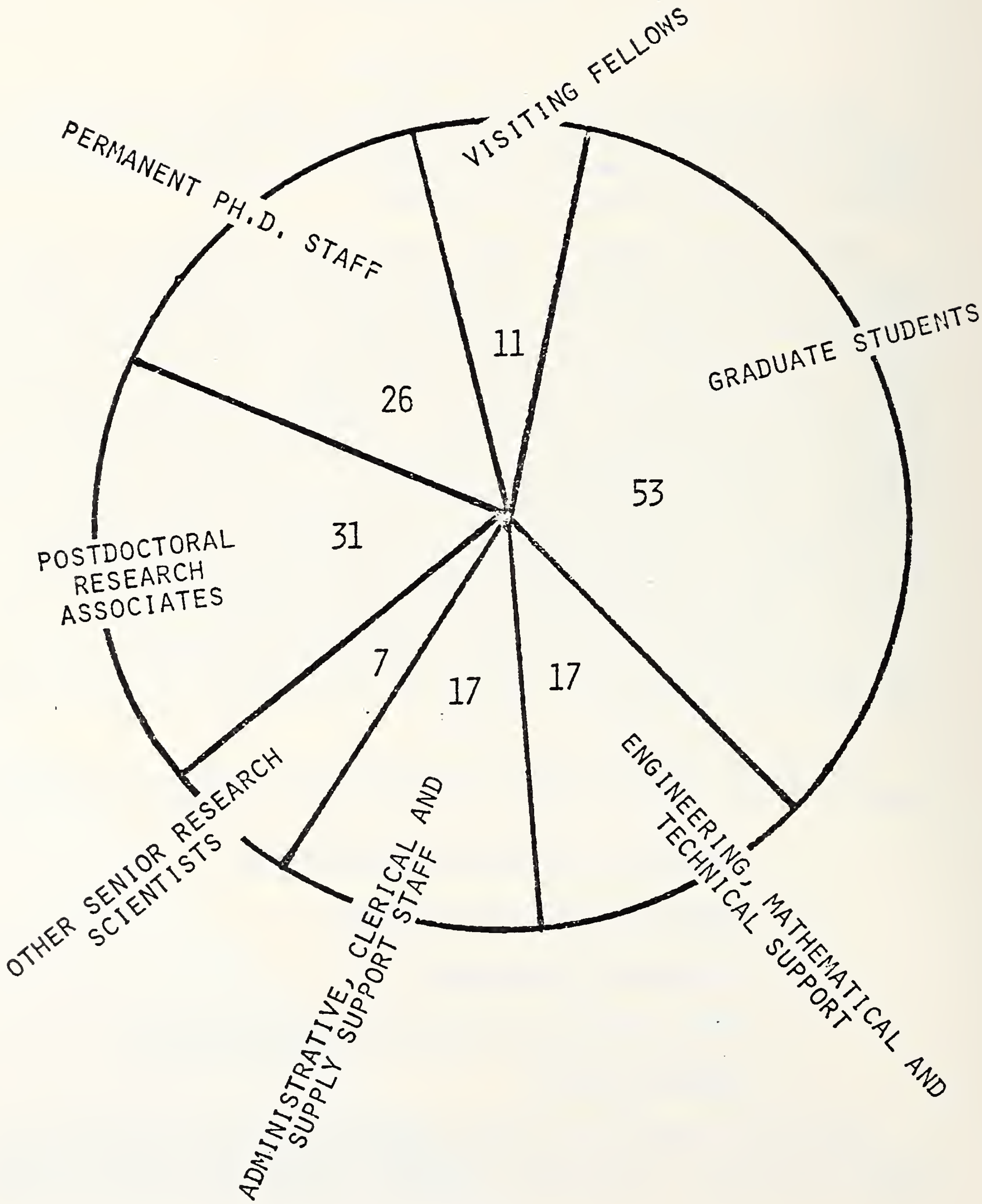



Figure 1.

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 any special privileges or liabilities deriving from participation in JILA or from designation as a Fellow.

As a result of the recent Reduction in Force at NBS, a senior scientist at JILA (Fellow) is being transferred to Division 524 (Time and Frequency). Two other Fellows of JILA on the CU Faculty are currently on leave for employment elsewhere and it is highly probable that this will result in resignation after a year's time. This is probably the largest decrease in number of Fellows in a single year during JILA's history.

One notes from the figure that of the 128 research scientists in JILA, that 84 (or 66%) are postdoctorals and students. Another 18 are visitors, for a total of 102 (or 80%) students, postdoctorals, and visitors. There is thus a high level of youthful vitality and turnover in the scientific staff, while providing at the same time for stability, maturity, and focus of programs through the Fellows of JILA. Five Ph.D.'s have been awarded with NBS thesis supervisors, and NBS Fellows have supervised 31 Ph.D. students during the past year as well as 33 postdoctorals (many have left, accounting for discrepancy of numbers with figure).

## Visiting Fellows Program

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 471 publications listed in the last three years' annual reports by QPD staff and Visiting Fellows, approximately 40% were by Visiting Fellows. This program again provided tremendous amplification of NBS staff. Visiting Fellows for 1980-81 and for 1981-82 are listed in Sec. III.

The program has managed to stay healthy and viable over the years, as NBS management (with support from the Evaluation Panels) has recognized the value of the program and given budget increases to help offset inflation. Specifically, $100 K is being added to the VF Program budget in October 1981 to make up inflationary losses in the regular Visiting Fellows Program. Further, in October 1982 an additional $100 K will be made available for exchange of scientists between JILA and Gaithersburg. It is expected that the "direction of visit" will alternate each year, with a JILA person going to Washington in 1982-83. This new program should enhance the communication and collaboration between JILA and NSBG -- a long sought goal often emphasized by our evaluation panels.

## II. TECHNICAL ACTIVITIES

This section contains brief narrative descriptions of research programs currently underway or recently completed. An alternative insight to these activities can be gained by reference to Sec. III where tables are found of publications, invited talks, Visiting Fellows, and seminars and colloquia, academic activities of NBS personnel, consulting, and technical and professional committee participation and leadership.

### Fundamental and Precision Measurements

Simple Stabilized Laser System. J. L. Hall, T. Baer and D. Bass continued development of a stabilized laser system at the simple, rugged and inexpensive end of the performance spectrum. Such devices are in great demand as laser sources of stable wavelength for dye laser wavelength interferometers (the <<Lambdameter>> invented by S. A. Lee and J. L. Hall), for the JILA gravity-measuring apparatus (J. Faller and M. Zumberge), for all routine interferometric testing, and for a variety of precision applications in astronomy, including calibration of high resolution astronomical spectrographs, and alignment of sophisticated polarization (Lyot) filters, etc. The JILA laser device is based on a frequency-pulling effect in a single mode HeNe laser in a longitudinal Zeeman field. The JILA approach is to measure the beat frequency between the two oscillating modes of opposite senses of circular polarization and servo-control the laser to the minimum. Although the beat frequency only changes by $\sim 10^{-4}$ of the optical frequency change, the beat signal has a very high information content since most perturbations affect the two polarization modes equally. The intermode beat is continuously counted into a reversible counter whose sense is switched synchronously with the applied square wave laser frequency modulation. Error information is strobed once per modulation cycle into a DAC for the servo. Performance of the system is remarkable, providing a frequency stability (Allan variance) well below $10^{-9}$ for only 1 second averaging time, and below $10^{-10}$ at 100 seconds. The drift of the system over time and with exchange of laser tubes is below $10^{-9}$. A systematic shift of $\sim 10^{-8}$ over the laser tube's life is expected due to pressure changes. The concept is to work with appropriate commerically-available tubes -- which have been designed and optimized for long life -- by attaching our piezo electric tuning control element with epoxy cement. Some useful experience is being obtained by building six of these units for projects in JILA and NBSB, NBSG (J. Faller, S. Smith, A. Gallagher, J. Bergquist, D. A. Jennings, and J. J. Snyder). The published work has attracted wide interest and requests for assistance. A patent application through NBS is being prepared (J. L. Hall, T. Baer and F. Kowalski).

Optical Heterodyne Saturation Spectroscopy. A major breakthrough in laser spectroscopy has come from the work of J. Hall, L. Hollberg, T. Baer, and Visiting Fellow, H. G. Robinson. In this new technique (Fig. 1), called Optical Heterodyne Saturation Spectroscopy, they use phase-modulation techniques to encode the resonance information of interest to a modulation frequency at which the laser noise has dropped to

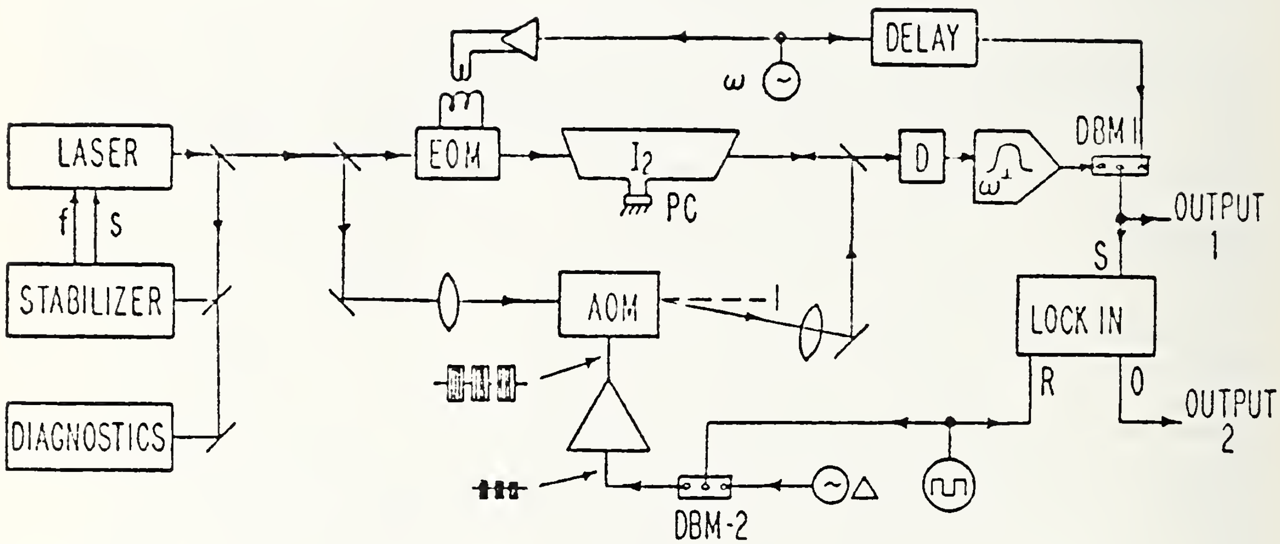



Fig. 1. Optical Heterodyne Saturation Spectroscopy. The frequency-stabilized single frequency laser output is divided into probe and saturating beams by a beam splitter. The probe beam is phase modulated by an Electro-Optic Modulator and passed through the Iodine cell whose pressure is controlled by the Peltier Cooler. The saturating beam, frequency offset and chopped by the Acousto-Optic Modulator, is collimated and aligned coaxial and antiparallel to the probe beam in the $I_2$ cell. The signal-bearing probe beam is detected by a fast photodiode (D) whose output is filtered for the rf component at frequency $\omega$ and applied to the signal port of an rf Doubly-Balanced Mixer. The rf reference signal is phase shifted by an adjustable delay line. The dc output of DBM-1 may be further processed by a lockin amplifier to recover the signal (output 2) synchronous with the saturation chopping.

near the theoretical minimum value associated with the photoelectron shot noise. For example, in demonstration experiments with dye laser measurement in $I_2$ vapor, the noise was reduced by about 10,000-fold in comparison to conventional saturation spectroscopy. They have shown that under realizable conditions, the sensitivity of measurement approaches the limit associated with the intrinsic quantum fluctuation of the signal itself. Experiments to confirm this result are under way. A very important aspect of this technique is that the absorption signal is received by an optical heterodyne process. The "local oscilator" signal provides "conversion gain," in the language of the radio engineers. The result is that quantum-counting spectroscopic sensitivity should be available well into the infrared where detector limitations would otherwise totally prevail. T. Baer and J. L. Hall have already applied the technique to stabilizing a cw color center laser at 2.6 μm with which excellent high resolution hyperfine-resolved spectra of HF were obtained for several P-branch lines. Application of our "traditional" (= state of the art) frequency offset lock techniques for long-term control and scanning of this color center laser will allow precision measurement of all the hyperfine interaction constants. Their variation with vibrational and rotational excitation carries important signature information about deviations from the Born-Oppenheimer limit of electronic-vibrational separability. Such information could well have a synergistic effect with direct investigations of intramolecular energy transfer processes that influence selectivity in laser isotope separation and bond-specific laser chemistry schemes. Interaction with the ion spectroscopy interests of S. R. Leone and D. Nesbitt is planned.

From the standards point of view, the new optical heterodyne spectroscopy technique is the most exciting development since the introduction of saturated molecular absorption spectroscopy (Barger and Hall, 1968). Robinson and Hall have shown theoretically that the resonance profiles in optical heterodyne spectroscopy should be based on a simple dispersion shape and should be rigorously odd-symmetric with respect to their center frequency. The experiments of L. Hollberg, T. Baer and J. L. Hall confirm the line shape prediction and pure symmetry to within 1 part in 500. New experiments on the metrologically-important $I_2$ line at 612 nm are being conducted by Ma Leung Sheng and J. L. Hall. The high sensitivity of the method has a side benefit in that one can work at much lower light intensities than those conventionally employed in $I_2$-stabilized lasers, thus avoiding the disastrous light shifts that dominate the reproducibility of these devices. Detailed information on this new technique has been provided to Alan Pine (NBSG) to facilitate his search for $Se_2$ and $Te_2$ resonances useful for stabilizing the argon green and blue laser lines.

Relativistic Time Dilation. Progress on the longitudinal interaction experiment of J. L. Hall, P. Nachman, and M. Rayman to remeasure the Relativistic Time Dilation is good, but has been seriously hampered by inadequate funding. A funding initiative which would have allowed this work to go forth in an aggressive manner now appears doomed to be cut out. Hall's group does in fact have the fast ion beam up and running, and they have studied the formation of well-focused ion beam images using a phosphor screen. The next step is to load the Na charge transfer over and measure the collimation of the resulting metastable beam via resonant laser excitation. After the laser, ion beam/fast neutral beam, and interaction techniques are developed and proved out, they will be measuring the absolute optical resonance wavelength for transitions of the fast-moving metastable atoms ($Ne^*$ first, then $He^*$). This will provide vastly improved spectral information for both atoms. At 50 keV, the first order Doppler shifts are ~20 Å (2.5 THz) which they expect to be able to measure to ~10 kHz, a fractional accuracy approaching $10^{-9}$. The second order shift associated with Relativistic Time Dilation for He will be 6.8 GHz which should be measurable to $\sim 10^{-6}$. This will represent a $10^3$-fold improvement over the present limit inferred from muon decay. The metrological technique to be employed is high resolution Fabry Perot Interferometry, using a free spectral range ≈100 MHz a finesse of ~75 (silver mirrors). The little Lambdameter has enough accuracy to identify the order number uniquely without tedious counting. In locking to Fabry Perots of similar line width they have already demonstrated a 20 Hz/min drift rate, made possible by the new fm sideband locking technique. Finally, it should be possible to set a new and very tight limit $\sim 10^{-9}$ on any vector dependence of the speed of light. If sufficient linear distance can be obtained in a laboratory to provide an attractive interaction time, it will be interesting to make the same measurements with the faster moving $H^*$ atoms.

New Limits for Lambdameter Accuracy. A major breakthrough in frequency metrology has recently been made by J. J. Snyder (NBSG) and applied to the high resolution JILA Lambdameter by J. J. Snyder, J. L. Hall, T. Baer, and L. Hollberg. In the JILA Lambdameter, the idea basically amounts to computing the wavelength average over a large number of overlapping but independent measurement intervals. The available $\sqrt{n}$ enhancement is quite interesting when the number of fringe measurements is $\sim 10^6$-$10^7$. A first hybrid software/software version was tried with the JILA Lambdameter and showed real promise. The main consequence is that the high data rate will make feasible a detailed clarification and (hopefully) removal of the interferometric errors of the system. Repeatability and resolution above $10^{10}$ were easily demonstrated, and wavelength accuracy of $10^{-9}$ was achieved. The intention is to pursue this real-time interferometric wavelength measurement technique to new limits.

Gravitational Waves. A new conceptual design for a gravitational wave detection experiment in space has been developed by J. E. Faller and P. L. Bender. It utilizes the equivalent of a Michelson interferometer, with spacecraft A at the center and spacecraft B and C about $10^6$ km away at the ends of the two arms (see Fig. 2). Doppler measurements are made over each arm, using roughly 50 cm diameter transmit/receive optics and visible helium-neon lasers with output powers of a milliwatt or less. The lasers at B and C are phase-locked to the received signals from A, and the phase of the received signals at A with respect to the lasers at A are recorded.

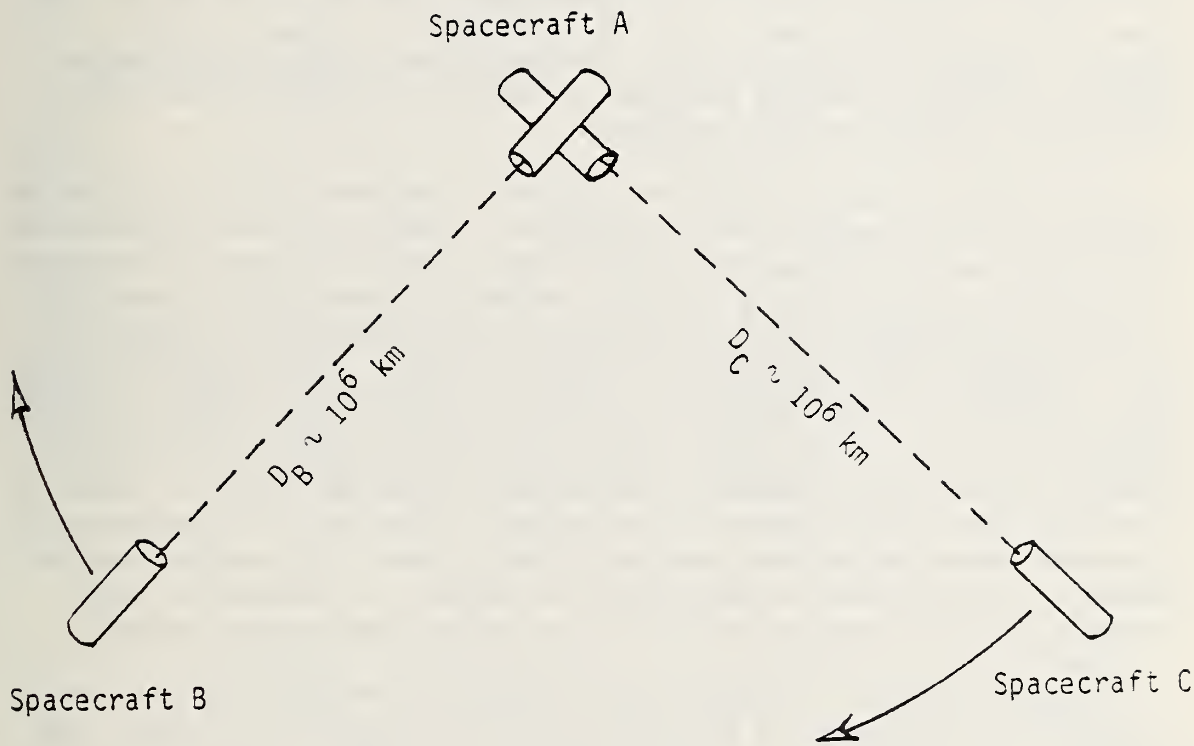



Fig. 2. Schematic diagram of gravitational wave detection experiment in space.

The orbital geometry is chosen so that each arm will stay constant in length over a year to 0.1%. Spacecraft A is placed about 2 × $10^7$ km ahead of the earth in a coplanar circular orbit around the sun with one year period. Spacecraft B and C are placed in similar one-year period orbits about the sun, with e = 0.003, i = $\sqrt{3}$ e, and nodes differing by 90%. With proper initial longitudes, spacecraft B and C will stay in a reference plane through spacecraft A which is defined by having the normal to the plane always point 30° below the direction to the sun. The directions to B and C from A will be orthogonal, as shown in Fig. 2, and they will appear to rotate in the reference plance with annual period. The main limitation on the constancy of the arm lengths is due to orbital perturbations by Jupiter and Venus.

There are two main objectives for the experiment. One is to search for gravitational wave pulses with periods of minutes to a few hours and with fractional strain amplitudes of roughly $10^{-20}$ or larger. The detection of such pulses would provide an entirely new and unique capability for studying events in the universe that involve very large masses. This includes present collisions of massive black holes, which may exist at the centers of many galaxies and probably provide the energy source for quasars, as well as collisions of such objects during the earlier history of the universe when galaxy formation was taking place. The second objective is to detect continuously emitted gravitational waves from both known and unknown rotating binary stars. The sensitivity needed to be confident of detecting such signals in the period range of minutes to a few hours is $10^{-21}$ in a one-day measurement interval.

The main factor that makes the achievement of such sensitivities possible is the absence of substantial gravitational forces due to the sun and planets with periods in the range of interest. For this reason, the apparent changes in the length of one arm of the interferometer can be used to determine changes in the laser frequency for periods considerably longer than the 6 sec round-trip travel time but less than days. It appears feasible to correct for such laser frequency variations with an accuracy of better than $10^{-18}$, so that the effect of laser instability on determining the difference in length of the two arms of the interferometer can be reduced to below $10^{-21}$.

Conceptual studies are now being started on the problem of shielding the test masses between which the distances are being measured from solar radiation and the solar wind without introducing other disturbances. The major forces of importance acting on test masses inside their shields are likely to be the following: fluctuating gradients in the thermal radiation pressure due to temperature variations in the shield; varying gravitational forces due to gradients in the gravitational field from the shield and relative motion of the shield due to time-varying forces on it; and fluctuating electrical and magnetic forces. It appears that such effects can be reduced to acceptable levels, but substantial studies of the associated problems are needed.

J. L. Hall has established a working level cooperation with the Cal Tech and Glasgow groups interested in gravitational antenna research (K. S. Thorne, R. W. P. Drever, S. A. Lee, and J. Hough). They have had numerous discussions about fundamental principle limits and ways to avoid them; although, of course, the strongest interaction has been in the area of laser stabilization. A paper in the final stages of preparation will describe the joint experiment at JILA in which a dye laser line width below 100 Hz was demonstrated.

Eötvös Experiment. P. Keyser and J. Faller have under construction a large (50" diam) torsion pendulum apparatus (see Fig. 3) with which to test for the equivalence of gravitational and inertial mass. This large Eötvös apparatus utilizes the surrogate fluid fiber which was developed at JILA, and which was used in the earlier (and smaller - 0.25 m diam) Eötvös apparatus of M. Keiser and Faller. The new apparatus is designed to take advantage of sensitivity increase (which scales as the diameter of the apparatus to the five-halves power) with size for this type of apparatus. This apparatus is now in the final stages of construction. During the past year a number of practical problems have arisen as a result of having increased the size of the apparatus. For example, a hydraulic jack was used to deform the top of the float just past its elastic limit so as to improve its roundness from the "as received" ±0.014" to ±0.004". Also the 95 lb. Zn test mass castings proved to be not nearly as non-magnetic as the Zn sample had led us to expect; as a result they were rejected and we are replacing them with OFHC Cu test masses.

Of the various noise sources identified in the earlier experiment of Keiser and Faller, only the effect of the residual mass-quadrupole moments can be expected to be substantially worse in the new apparatus. These effects can be ameliorated by measuring the quadrupole moments of the float and systematically tuning them out (as they did) by mass tuning; or one can remove their effect on the data by directly measuring the changes in the gradients of the external gravitational field and then correcting the float's response for these changes. In the case of the new float, it is planned to use both methods.

Geophysical Measurement Development

Gravity Gradiometer. Recognizing the needs of the Eötvös experiment as well as the potential of this type of fluid supported pendulum apparatus as a gradiometer, Faller is proceeding at present with the testing of two 0.25 m diam (see Fig. 4) fluid gradiometers. This development -- in addition to its importance for our Eötvös work -- is seen to have application to tunnel and intrusion detection as well as security for nuclear stockpiles.

This group has developed a new optical angle-detecting system (Fig. 5) for use both with the gradiometer and on the large Eötvös apparatus. This "internal" sensing system promises to have a much higher mechanical integrity -- the sensing optics are a part of the container lid on which the zero-determining electrode array is located -- then the external auto-collimator approach used in the earlier work.

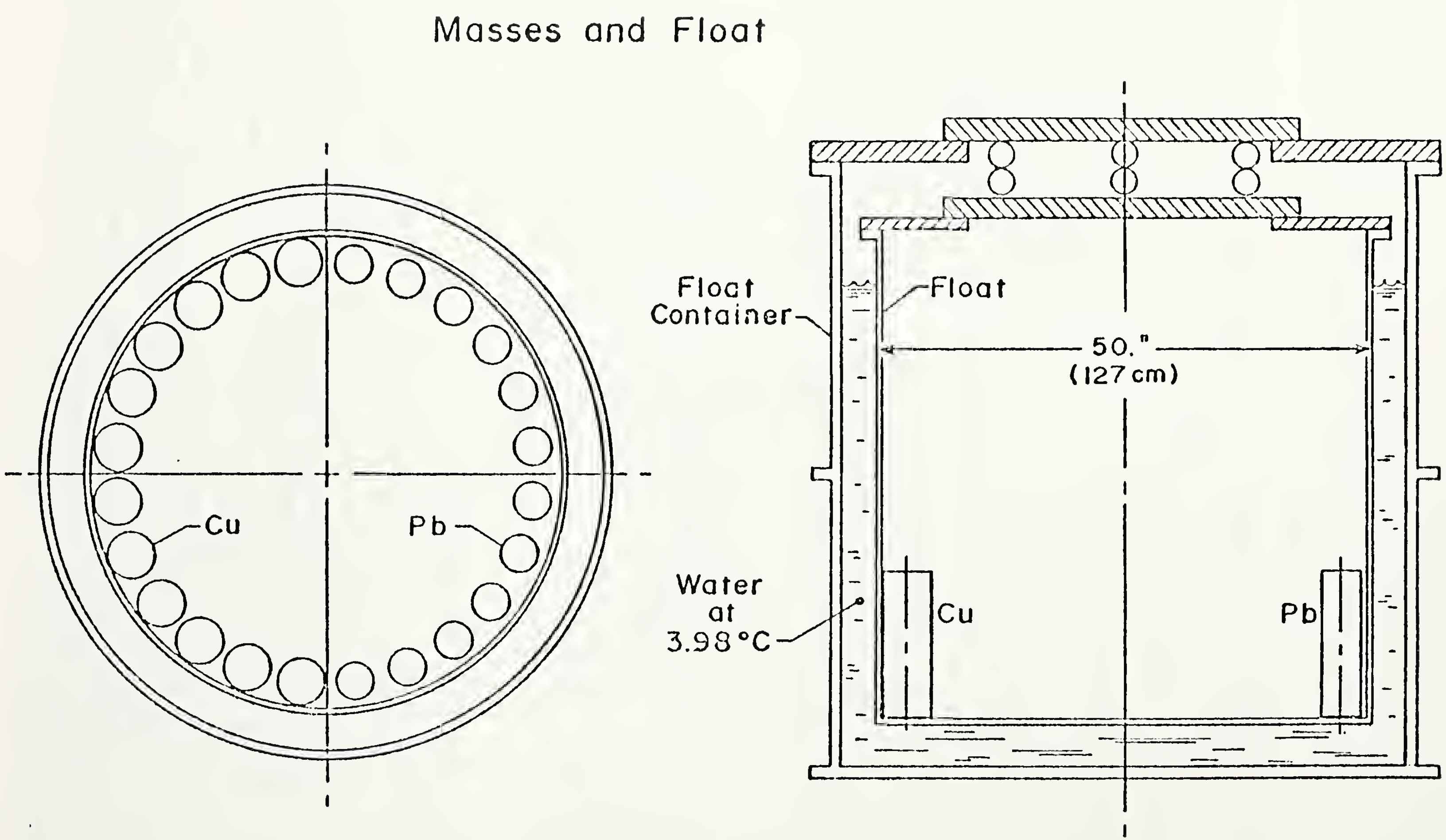



Fig. 3 Large (1.3 m diam) torsion pendulum apparatus to test equivalence of gravitational and inertial mass.

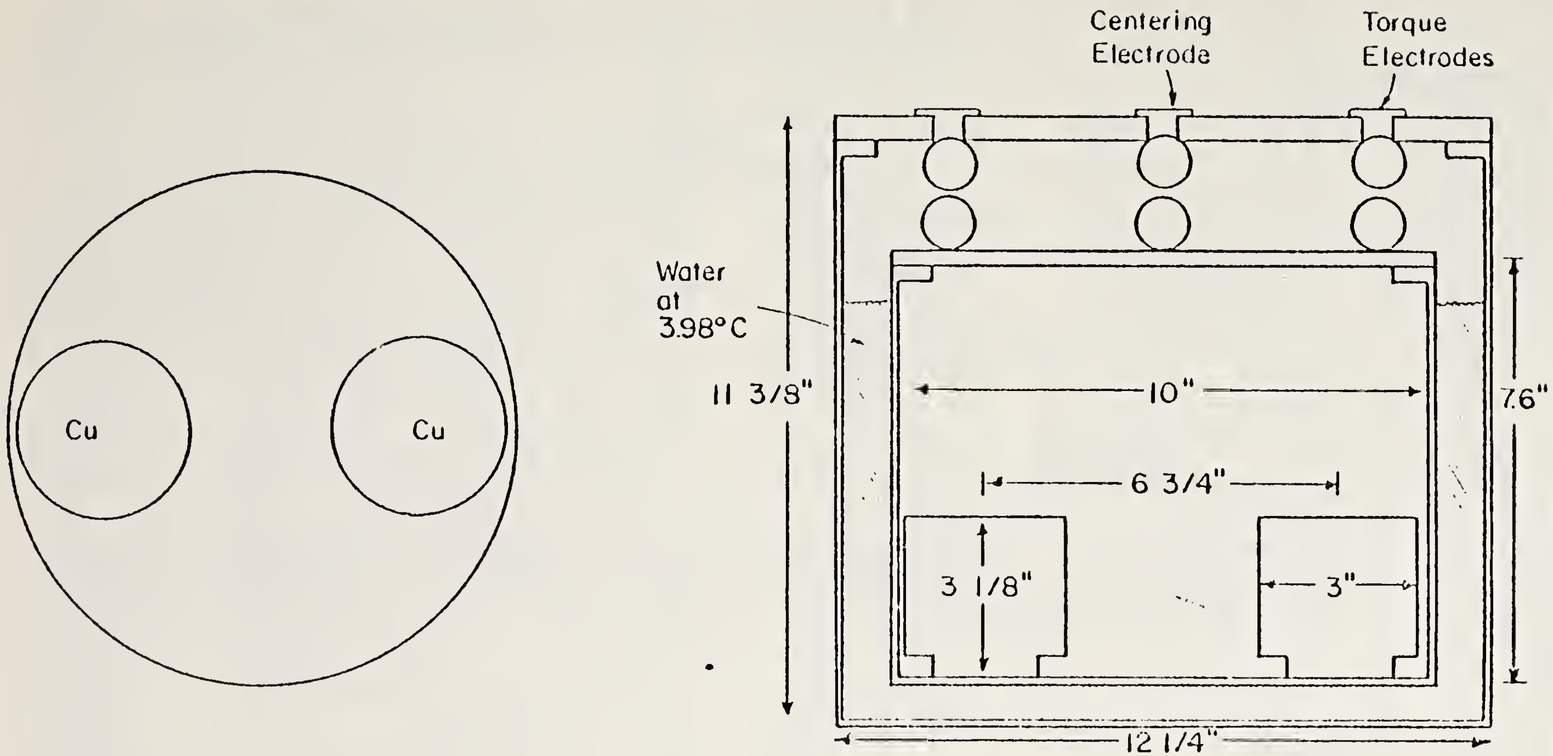
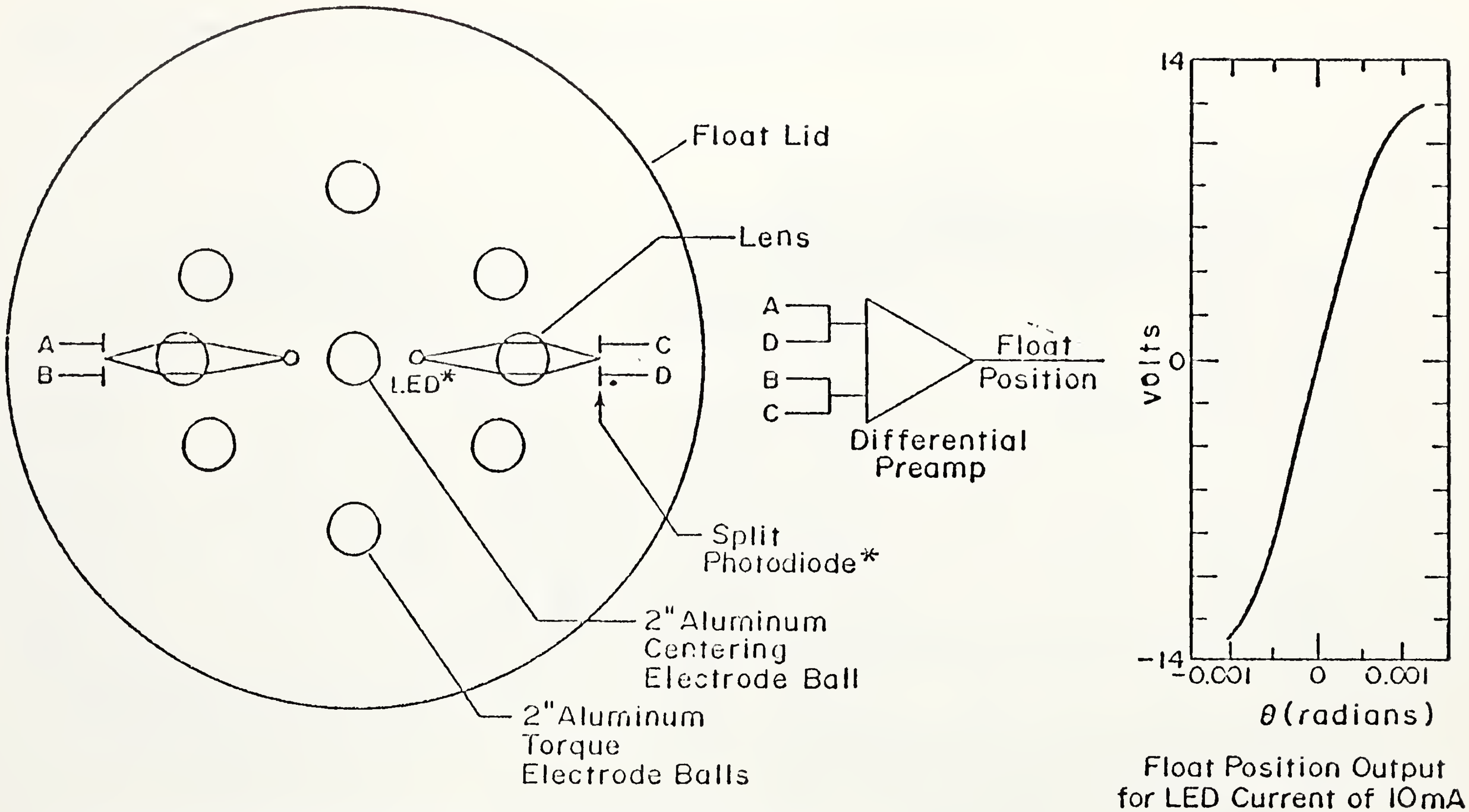



Fig. 4. Schematic of 0.25 m diam fluid fiber gravity gradiometers.

Optical Detection System




*(LEDs and Split Photodiodes are rigidly attached to the underside of the Float Container Lid.)

Fig. 5. Schematic of angle-detecting system for integration into Eo"tvo"s and gravity gradiometer apparatuses.

The sensing system consists of an infrared light emitting diode-IR LED (whose output light is focused into a line image by a cylindrical glass "lens" attached to the type of the float) and a split photodiode detector. As the float turns, the cylindrical lens moves with respect to the LED-photodiode pair causing the line image to move its position in the split photodiode giving rise to a rotation-dependent voltage as shown on the right half of Fig. 5. Locating detection systems on opposite sides and using their outputs properly summed makes this detection system insensitive to sideways motion of the float without sacrificing its sensitivity to rotation.

Absolute Gravimeter (g). Over this past year, J. Faller has continued the development of a new absolute gravimeter. The absolute determination of g, the acceleration due to the earth's gravity, has long been a measurement of considerable importance. While the value of g continues to play a significant role in the determination of certain physical constants and standards, with the accuracies obtainable today, its measurement now has broad applications to geophysics. At JILA, M. Zumberge, J. Faller, and R. Rinker have developed a new absolute gravimeter which was designed to be portable so that it could be used in field applications (see Fig. 6, photograph of apparatus).

Three innovations have contributed to the successful development of the new JILA apparatus that has been developed over the past few years: (1) the addition of a coaccelerating chamber which drops with the corner cube, (2) the development of the "super spring" that provides a compact, stable long period spring for isolation purposes, and (3) a newly implemented Zeeman stabilization scheme devised at JILA which has been used to stabilize the He-Ne laser that serves as the light source in the interferometer.

Questions relating to the accuracy of this new instrument have been for some time and continue to be under study at JILA. At this time the best estimate of the error budget is given in Table 1.

This past year 400 sets of 150 drops were made, during which the system appeared to be operating correctly (e.g. the apparatus was not being subjected to any special test conditions). The standard deviation of the results of these 400 data sets is 5.9 μgal or about 6 parts in $10^9$, while the standard error associated with a single 150 drop data set ranges from 3 to 7 μgal. This coming October an intercomparison of absolute gravimeters (Sakuma's stationary apparatus, the new instrument developed at JILA, the absolute gravimeter of the USSR Academy of Sciences, and the AFGL instrument of Dr. Hammond) is planned at the Bureau International des Poids et Mesures (BIPM) in Sevres, France. The results of this intercomparison should help to further clarify the issue of instrumental accuracy.

Recognizing that broadly based usage is the one and only way to answer questions of geophysical import as well as actual instrumental field performance, it is planned to follow-on this development by seeing that this new type of gravity instrument is both widely used and field

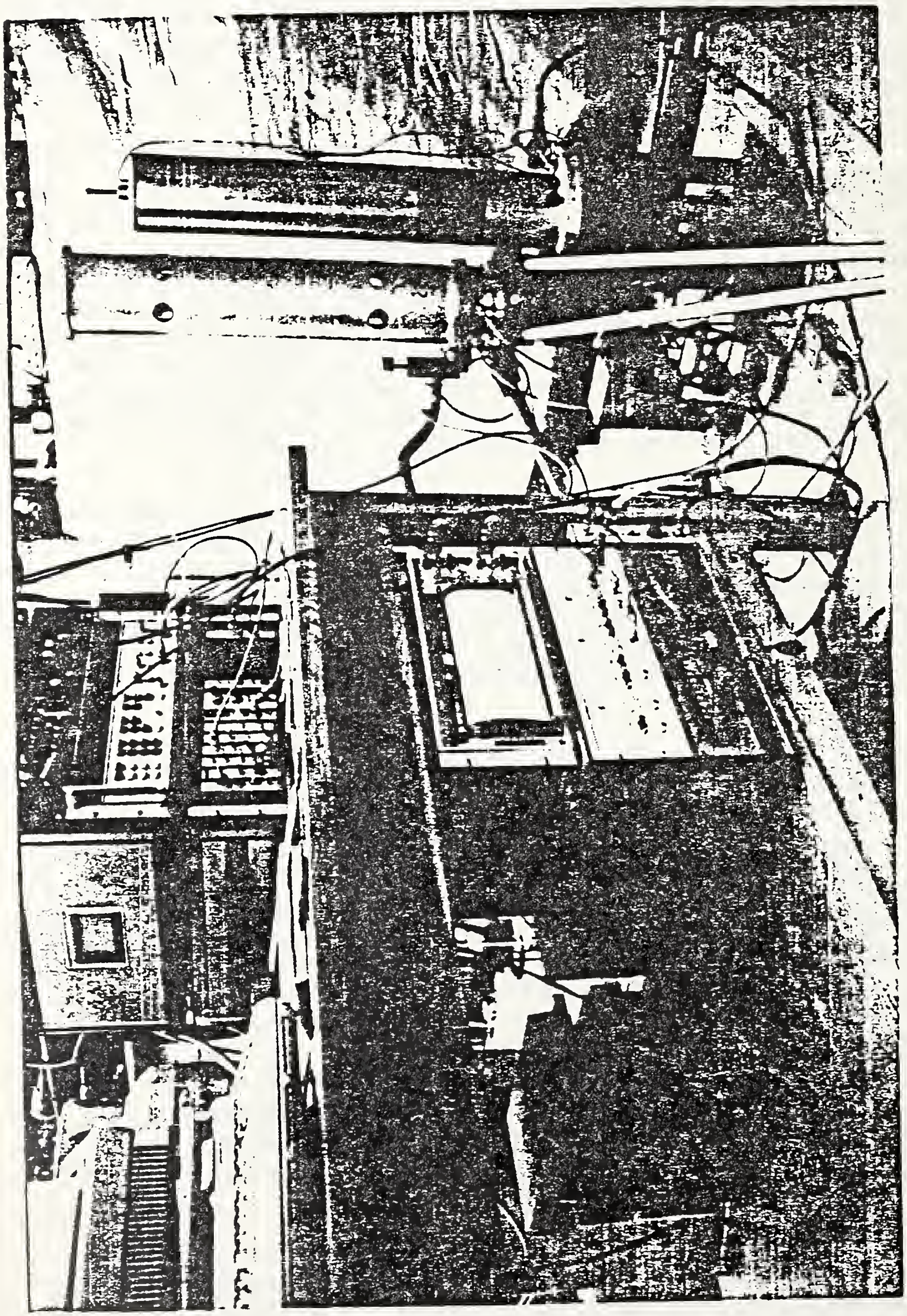


Fig. 6. Photograph of portable absolute gravimeter for accurate measurement of g.

Table 1

Known Systematic Errors

| Source | Error |
|---|---|
| Differential Pressure | 1.0 μgal |
| Differential Temperature | 1.0 |
| Magnetic Field Gradient | 0.5 |
| Electrostatics | 1.2 |
| Attraction of Apparatus | 0.5 |
| Vertical Reference | 0.8 |
| Optical Path Changes* | 3.8 |
| Laser Wavelength | 1.0 |
| Rotation | 1.0 |
| Translation | 1.0 |
| Floor Recoil | 1.0 |
| Phase Shift | 1.0 |
| Frequency Standard | 0.5 |
| R.M.S. Total | 4.2 μgal |

*This error is primarily due to problems associated with the pelicle on the bottom of the drag-free chamber having a finite wedge angle. At the present time we are exploring a number of possibilities (including the possibility of completely eliminating the pelicle) with the aim of reducing or eliminating this error source.

tested in as many different geophysical settings as possible. Hopefully we can look forward to an era in which precision measurements of g will prove to be an exciting new tool for furthering our understanding of the world on which we live.

Short Wavelength Variation in "g." The problem of using satellite measurements to determine variations in the earth's gravitational field with wavelengths of about 100 km and somewhat shorter has been studied by Bender and Faller. The NASA Office of Space and Terrestrial Applications is considering requesting a new start in FY/83 or FY/84 for a mission called GRAVSAT, which involves microwave Doppler measurements between two spacecraft in the same low polar orbit around the earth and separated by up to about 300 km. Gravity gradients in the along track direction would change the relative motion of the two spacecraft, and worldwide measurements of the velocity data would determine the global gravity field for wavelengths of longer than 100 km. The approach suggested for consideration by Bender and Faller is the use of laser Doppler measurements between the spacecraft to improve the accuracy, and therefore the short wavelength gravity field resolution. This also would require improvements in the systems aboard the spacecraft for avoiding spurious accelerations due to atmospheric drag and other effects.

Deep Borehole Tiltmeter. J. Levine (Fellow of JILA rostered in NBS Div. 524), in collaboration with J. C. Harrison and C. Meertens of CIRES and the University of Colorado, have developed a deep borehole tiltmeter which can be operated below the near surface layers so as to reduce the influence of meteorological effects and which is relatively inexpensive to build and to install. A depth of 33 m is normally used, although this is not a critical aspect of the design, as the electronics are inside the instrument capsule. The instruments are capable of operating unattended for long periods of time at tidal sensitivity. Six of these instruments have been installed at two sites near Boulder, Colorado. One site is at the edge of the foothills with closely spaced holes 6 m, 16 m, and 33 m deep. The other site is 24 km to the east in the flat plains where five holes, each 33 m deep have been drilled spaced from 30 m to 120 m apart. Using an observation time of 28 days, earth tides are observed with a signal-to-noise ratio of almost 40 db and with an apparent secular tilt of about 0.1 micro-radian/month. Data from the instruments are used to construct the tidal admittance and to study the coherence among the instruments. The semi-diurnal tidal admittance shows very good agreement with theory. Consecutive monthly admittances average 0.984, show a standard deviation of approximately 6% and have no secular trend. The instruments show no nonlinear behavior. They are currently requesting permission to deploy approximately ten additional instruments in Yellowstone National Park to study the known low-velocity anomaly there and along the Wasatch Fault near Ogden, Utah to investigate a possible seismic gap in that area.

Multiple Wavelength Geodimeter. J. Levine and J. Magyar of the Time and Frequency Division are developing a multiple-wavelength distance measuring system designed to measure distances of order 40-50 km with an uncertainty of about 0.02 ppm. The instrument is currently undergoing laboratory tests, with the first field tests planned for this winter. The first field tests will be made over short baselines in Colorado. These tests will be used to test the phase-measuring system in the presence of realistic levels of atmospheric turbulence. They will also be studying the degradation in the microwave system due to spurious reflections ("ground-swing"). (Levine is a physicist in the Time and Frequency Division and is also involved in other projects in collaboration with others in that division including various problems involved with the NBS time scale and with time coordination. In particular he has been responsible for generating UTC(NBS) and is currently developing software and hardware for a new NBS time scale system.)

## Astrophysical Measurement

Diagnostic Techniques for Stellar Atmospheres. Astronomers have been developing powerful techniques for inferring such physical properties as temperatures, densities, and departures from excitation and ionization equilibrium in the hot plasmas found in the outer atmospheres of the Sun and stars. These techniques involve comparing observed spectral lines and line ratios primarily in the ultraviolet with profiles computed by solving the equations of radiative transfer and statistical equilibrium for a realistic model of stellar atmospheres. During the last year Linsky and his colleagues have derived physical models for the chromospheres of different types of stars by analyzing ultraviolet emission lines of $Mg^+$, $C^+$, $Si^+$, $C^{++}$, and $C^{+++}$. They have also found that the ultraviolet A-X bands of the molecule CO can fluoresce in the chromospheres of cool stars when pumped by the resonance lines of neutral H, C, and O (see Fig. 7). They found that the relative line intensities among the intersystem lines of $C^+$ near 232 nm are useful density diagnostics for stellar chromospheres, and that the 164 nm subordinate line of $He^+$ is formed primarily by recombination in the solar chromosphere and thus is a good indicator of the photoionizing flux of X-rays. An important problem for next year will be the study of the $L\alpha$, $L\beta$, and $H\alpha$ lines of hydrogen using the theory for frequency redistribution in this coupled system of lines being developed by J. Cooper.

What Types of Stars are Solar-Like? The outer atmosphere of the Sun is now known to consist of a chromosphere ($T \approx 10^4$ K), a $10^6$ K corona with a very small mass loss rate, and a geometrically thin transition region between the chromosphere and corona. Based on X-ray observations with the Einstein X-ray Observatory and ultraviolet spectra from the International Ultraviolet Explorer satellites, Linsky and his colleagues are now able to determine the range of stellar effective temperatures and gravities in which stars have outer atmospheres similar to the Sun. They also found that stars with somewhat lower effective temperatures and gravities no longer have hot coronae and transition regions, but rather have only cool chromospheres and large rates of mass loss (see Fig. 8). During the next year they will study the energy balance in stellar chromospheres and coronae.

Measurement of Stellar Magnetic Fields. Linsky and his colleagues are now pursuing two methods for measuring magnetic fields in stars. The first method involves measuring the Zeeman triplet splitting directly on the extra width of spectral lines with large Landé g factors compared to lines with small g factors in high resolution unpolarized spectra. The second method involves the analysis of 6 cm radio emission from stars formed by the gyroresonance emission process (low order harmonics of the cyclotron frequency of electrons spiraling in coronal magnetic fields). This second technique became feasible when Gary and Linsky discovered radio emission from solar-like stars for the first time (see Fig. 9) using the Very Large Array radio interferometer of the National Radio Astronomy Observatory.

Solar and Stellar Flares. Linsky and his colleagues are studying flares on the Sun using experiments on the Solar Maximum Mission satellite and stellar flares using the Einstein X-ray Observatory and the International Ultraviolet Explorer satellites. The principle question they are trying to answer is whether flares cool primarily by radiation (X-rays and ultraviolet), thermal conduction, or expansion.

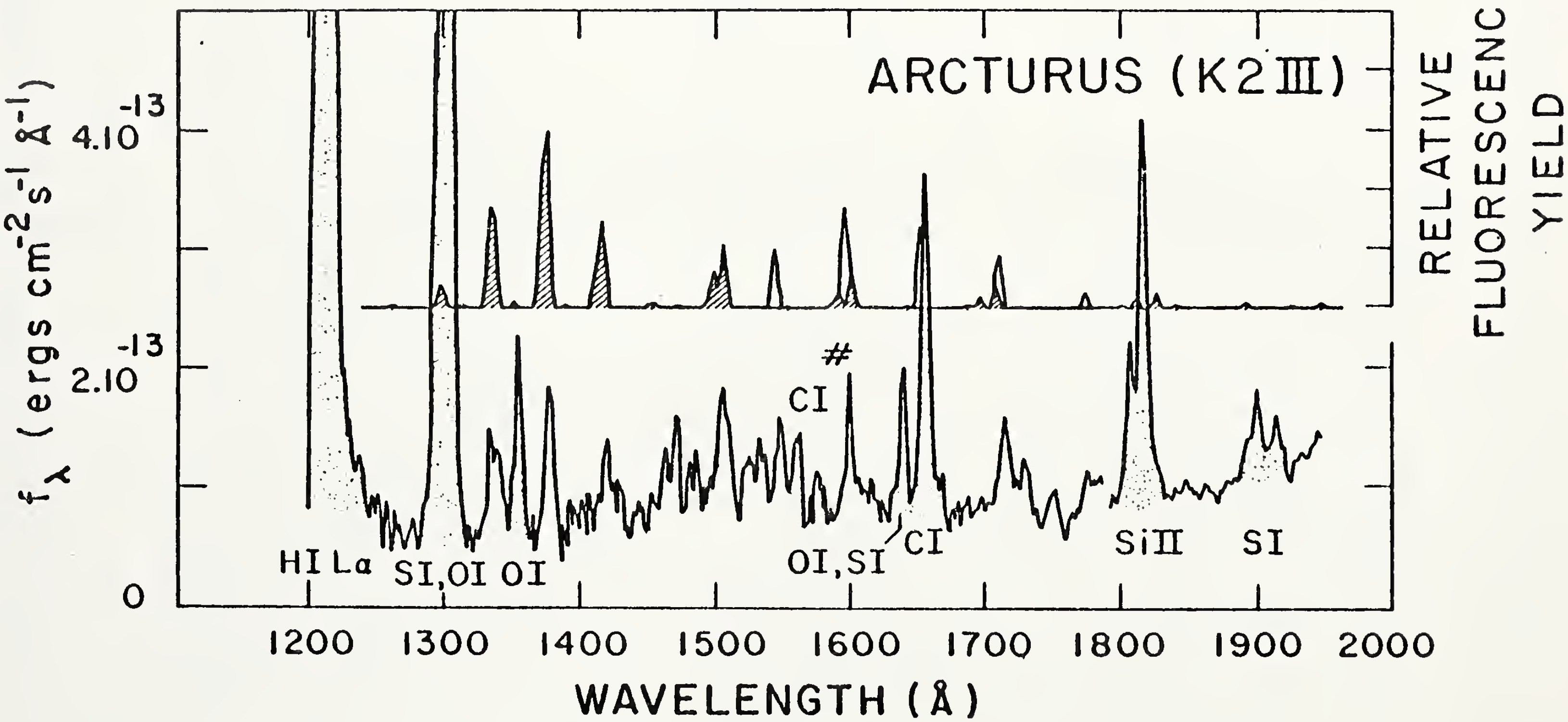



Fig. 7. Comparison of a theoretical fluorescence spectrum of the A-X band of CO as pumped by resonance lines of H, C, and O (top band) with the observed ultraviolet spectrum of the star Arcturus (bottom band). Many of the heretofore unidentified features in the ultraviolet spectrum of Arcturus and other stars can now be identified as due to fluorescence of CO.

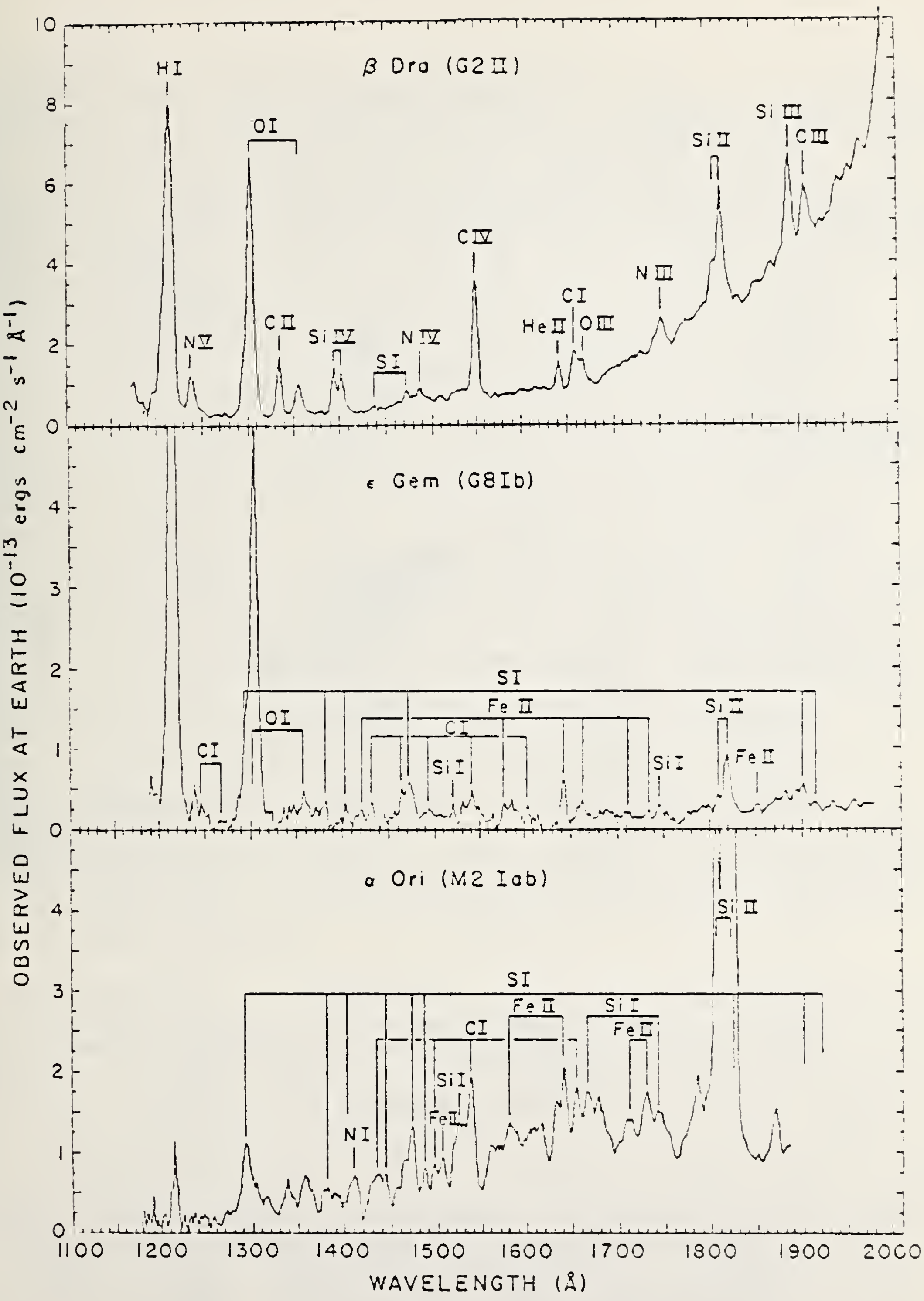



Fig. 8. Ultraviolet spectra of the stars β Dra, ε Gem, and α Ori obtained with the International Ultraviolet Explorer satellite. Note that β Dra shows emission lines of highly ionized species such as N V ($N^{+4}$) and C IV ($C^{+++}$), indicating a solar-like outer atmosphere. On the other hand, both ε Gem and α Ori show no evidence of highly ionized species and thus have only cool matter in their chromospheres.

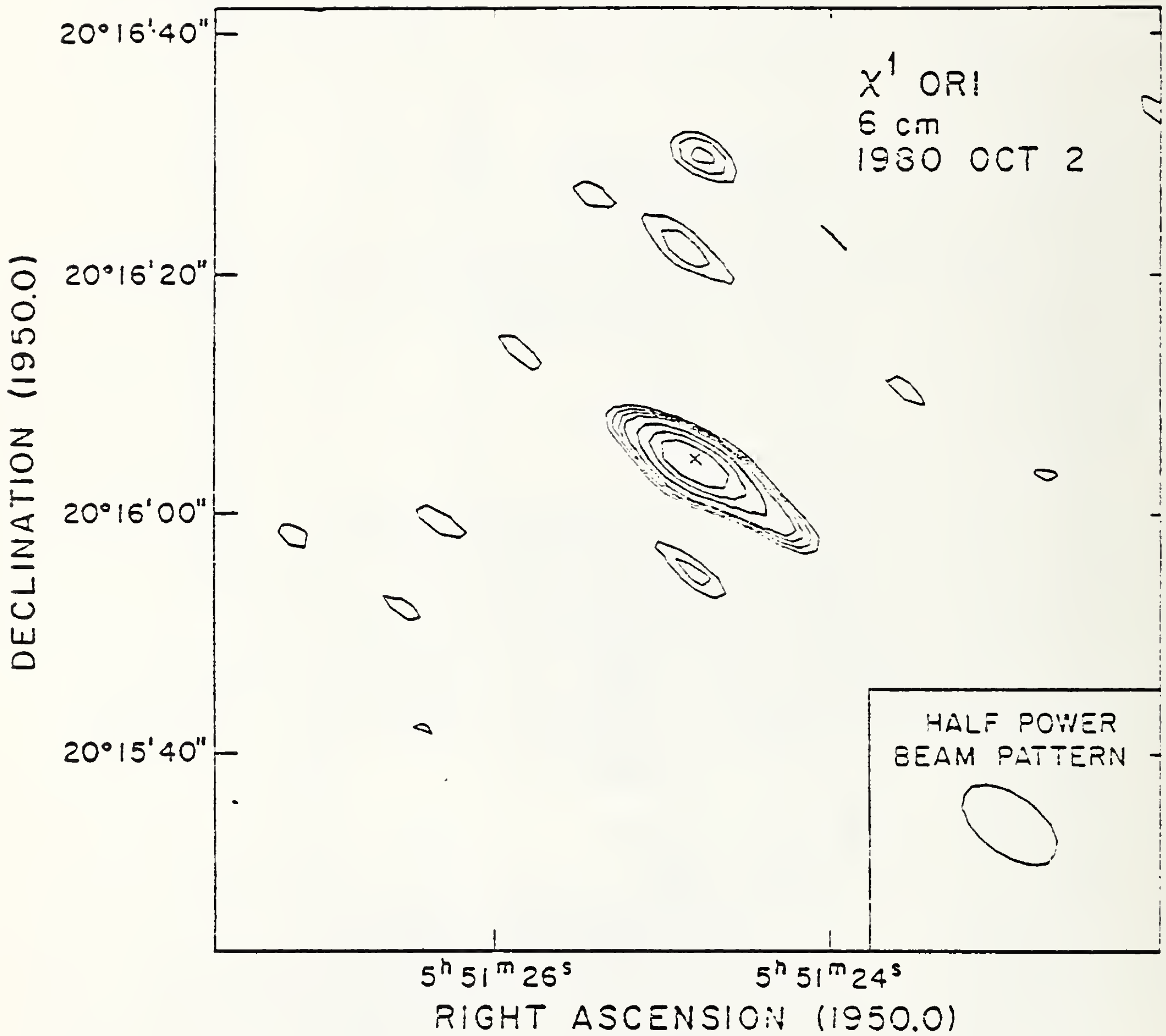



Fig. 9. First discovery of radio emission from a solar-like star with the Very Large Array radio interferometer of the National Radio Astronomy Observatory. This is a map at 6 cm wavelength indicating that the $\chi^1$ Ori is a radio source (× marks the optical position of the star). The emission is almost certainly due to the gyroresonance process indicating coronal magnetic fields of about 300 gauss.

Steady Flows in the Quiet Solar Transition Region. K. B. Gebbie, J. Toomre, F. Hill, in collaboration with L. J. November and G. W. Simon (SPO), have carried out an observational study of steady flows in the quiet solar transition region, as a guest investigator program on the Ultraviolet Spectrometer and Polarimeter (UVSP) experiment on the Solar Maximum Mission (SMM) satellite. Two dimensional images of intensity and Doppler velocity in spectral lines of C II, S IV and C IV were typically repeated for an entire orbit and the data time averaged to yield the steady component of the velocity field over a range of heights. The main results of this work are that: (1) the patterns of steady velocity in the three spectral lines are similar, suggesting not only that the same flow pattern extends from $2 \times 10^4$ K to $10^5$ K, but also that it persists without apparent evolution for a period of at least three hours. (2) Seen at disk center, regions of relative downflow tend to coincide with regions of bright network emission, while relative upflow occurs more often in the darker areas. (3) Histograms showing the numbers of spatial points with given velocity amplitudes are close to Gaussian with only a slight asymmetry toward higher amplitude downflows. (4) The real surprise in these data is revealed in scatter diagrams of steady vertical velocity versus intensity (Fig. 10), where the brightest points appear to form a separate branch with substantially lower velocity amplitudes than those of the primary branch. The presence of the two branches suggests that the downflow has at least two components. Since the primary branch is associated with the network as a whole, it seemingly includes both supergranulation and magnetic downflow; the secondary branch may form a separate, lower amplitude component of the magnetic downflow in the brighter sites. We are hardpressed to offer an interpretation of the two classes, largely because theoretical models of mean flows and waves along magnetic flux tubes are still in the early stages of development, as are the theories of penetrative convection relating to supergranulation.

Mesogranulation. The same research group has continued their study of the lifetimes, topology and height dependence of mesogranulation, in order to shed light on its origin and relation to other discrete scales of motion in the Sun. Further, it is now clear that these 5-10 Mm convective flows will make a significant contribution to all the photospheric and chromospheric velocity fields to be measured with the Solar Optical Universal Polarimeter (UVSP) on Spacelab 2 and with many of the proposed experiments on the Solar Optical Telescope (SOT). For any real advance in the understanding of mesogranulation, it is essential to obtain observations with good seeing for periods of 8 to 10 consecutive hours. In an attempt to improve the consistency of the data over such long periods, a number of substantial improvements have been made in both the observing strategy and the software. Sixty-minute running means of data obtained during such continuous observing runs indicate that the mesogranular lifetime is of order 3 hours.

Analysis of the Ultra-hot Wolf-Rayet Star Sand 3. D. H. Hummer has continued his analysis of the OVI star Sanduleak 3 with M. J. Barlow (London), using two IUE spectra and five AAT visual spectra. Hummer and Barlow have merged the spectra to obtain continuous coverage from 1145 Å

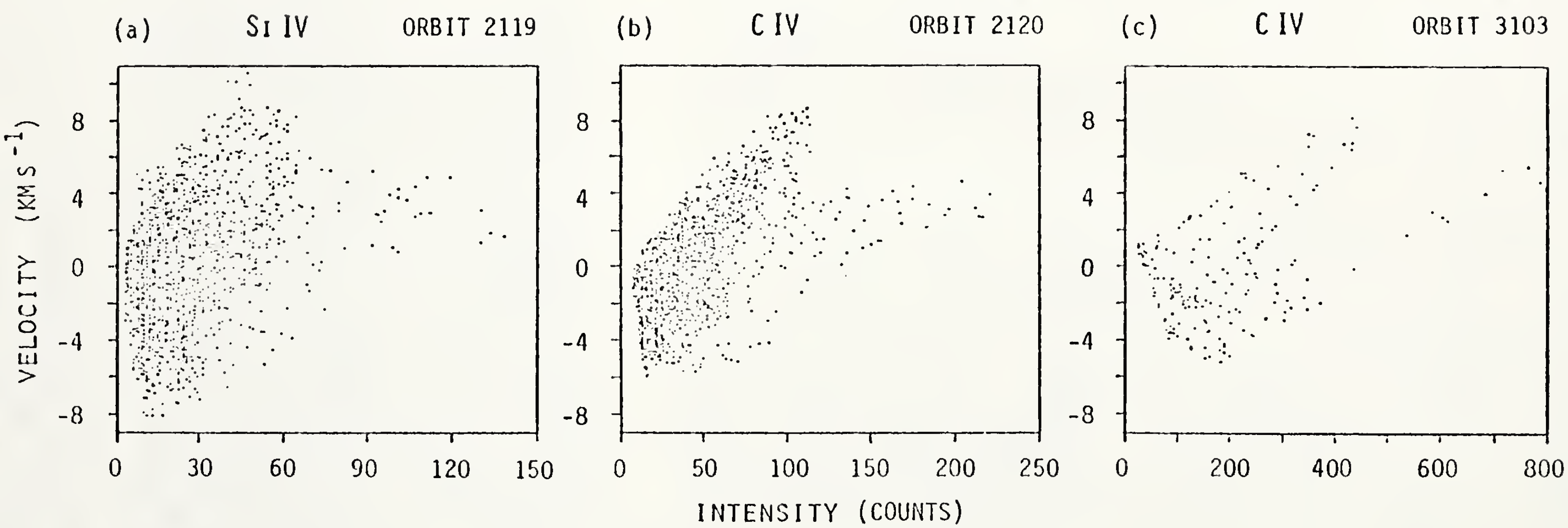



Fig. 10. Scatter diagrams of steady vertical velocity versus intensity formed from observations at disk center on the quiet Sun. The Si IV λ1393 data in panel (a) and the C IV λ1548 data in panel (b) were obtained by time-averaging 25 rasters covering a 120" × 120" area observed on 1980 July 4. The C IV data in panel (c) are the average of 50 smaller 120" × 15" rasters, which were observed on 1980 September 8 in order to obtain better photon statistics and time resolution at the expense of spatial coverage. The two distinct branches in each of these plots suggests that the downflow has at least two components.

to 7300 Å, and have dereddened the resulting composite spectrum by removing the 2200 Å feature, to obtain E(B-V) = 0.5. The resulting spectrum, shown in Fig. 11, shows no signs of deviation from a pure Rayleigh-Jeans ($F_\lambda \sim \lambda^{-4}$) throughout the spectral range of the observations. The very high temperature implied by this observation, together with the presence of emission lines of O VI, VII, and VIII, which Hummer and Barlow identified in 1979, and the absence of hydrogen and visual nitrogen lines implies that one may be seeing the bare core of a highly-evolved star that has recently blown off its atmosphere; the presence of the NV resonance line with a strong P-Cygni profile suggests that the ejected material is still relatively close to the star. Barlow and Hummer will be reporting at the IAU Symposium on Wolf-Rayet stars for September 1981 on this object as a prototype of a new stellar class, WO, which have evolved from WC stars.

The main effort at present is to determine the relative abundances of He, C and O using the emission lines of various ions of the elements; for this purpose radiative recombination coefficients and relative line intensities, allowing for collisions, are being computed for one, two and three electron systems. These codes have been written and largely debugged in collaboration with Dr. P. J. Storey (London) and will be used to prepare extensive tabulations of effective recombination coefficients, which will be invaluable in interpreting the high n ($\lesssim$20) recombination lines now being observed more and more frequently in the near infrared spectra of many types of stars and nebulae.

Analysis of Hydrogen Spectrum of Dwarf Novae. The escape-probability treatment of radiative transfer in spectral lines in a gas with a general three-dimensional flow field, which was developed several years ago by D. G. Hummer and G. B. Rybicki (Center for Astrophysics) is being used to calculate hydrogen line profiles formed in the accretion discs of dwarf novae. Although accretion discs are found in a wide variety of astronomical systems, the basic physics of viscous dissipation of Keplerian motion by which they are heated remains obscure. Dwarf novae are thought to be the most favorable system to study in order to understand this phenomenon; from a detailed study of the hydrogen spectrum it should be possible to estimate the heat input into the disc as a function of radius. This work is being carried out by a graduate student, Mr. Douglas Carroll, under the supervision of D. G. Hummer.

External Blanketing of Stellar Atmospheres. In view of the accumulating evidence that the ultraviolet color temperatures of hot stars is essentially lower than the effective temperature inferred from visual fluxes, D. G. Hummer is investigating the effect of stellar flux distributions of radiation either emitted or scattered back into the stellar photosphere by overlying material. As a first step, this mechanism was investigated schematically by considering a gray model atmosphere with a partially reflecting outer boundary with a wavelength dependent reflectance function. For certain simple forms of the reflectance function, this problem can be solved numerically with little effort; the results show that quite moderate back scattering by the winds in the ultraviolet

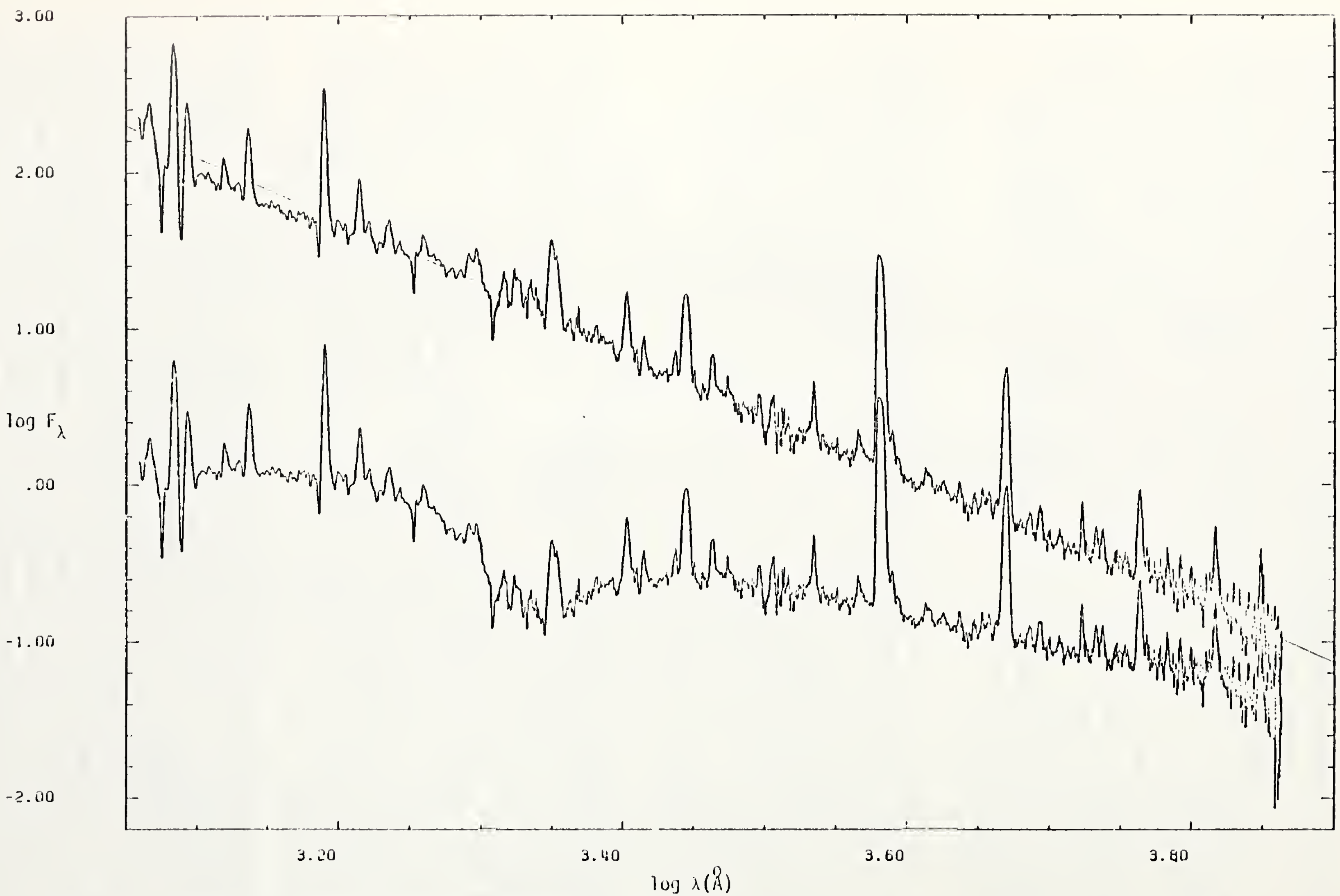



Fig. 11. Original (lower) and dereddened (upper) composite spectrum of Sand 3, showing the logarithm of the flux as a function of the logarithm of the wavelength in Å. Straight line is eye-ball fit of const. $\lambda^{-4}$.

can make the visual flux appear characteristic of hotter models, so that ignoring this effect would lead one to assign too high an effective temperature to the star. Typical results are shown in Fig. 12. A brief account of this work is being prepared for publication, and a more realistic calculation, using monochromatic wind opacities from David Abbott's wind models and the Auer-Mihalas non-LTE atmosphere code, is under way in collaboration with Drs. Castor and Abbott.

Escape-Probability Theory of Spectral-Line Formation. The generalized escape-probability theory, which was developed last year by D. G. Hummer and G. B. Rybicki (Center for Astrophysics) is valid for velocity fields of arbitrary amplitude, goes to known low- and high-velocity limits, and for the first time yields necessary conditions for the validity of the high-velocity (Sobolev) limit. This work has been submitted for publication. Hummer has recently generalized this theory to include, for the first time, the effects of continuous opacity on the line, and has obtained simple analytical results for several limiting cases most applicable to astrophysical modeling. This extension of the theory is important because it allows the use of escape-probability approximations in dealing with optically-thick media. In the next year, extensive comparison of the results of escape-probability calculations with accurate numerical solution of the transfer equation for a wide range of flow-speed gradients and optical thicknesses will be made to further refine our understanding of conditions for validity and of typical errors in the approximation.

Frequency Redistribution in Scattering. D. G. Hummer is continuing his long-standing research in the effects of partial redistribution on spectral line formation. A new formulation of collisional redistribution for non-general levels that has been developed by Ballagh, Burnett, and Cooper is being carried through, in collaboration with D. G. Hummer, to the point that it is computationally useful in astrophysical problems. A preliminary draft of this paper has been written.

The effects of partial redistribution on transfer in multiplets and in molecular bands will be investigated by Dr. Hummer, in collaboration with Dr. A. A. Kutepov, an exchange scholar from the Department of Atmospheric Science, Leningrad State University. The multiplet calculation is intended to examine the anomalous multiplet ratios caused by the differential effect of continuous opacity on strong and weak components. The molecular band theory will be applied to modeling of the 15 $\mu$ bands of $CO_2$ in the earth's atmosphere; this band will be observed by a satellite to be flown shortly carrying LASP instrumentation.

Festschrift for Professor M. J. Seaton. D. G. Hummer has been named a co-editor, along with P. G. Burke (Daresbury) and Ian Percival (London), of a book on atomic physics and astrophysics in honor of Professor Seaton's 60th birthday, which occurs in 1983. Contributions have been promised by a number of Seaton's colleagues and former students; Hummer is writing a chapter on "The Role of Atomic Physics in Stellar Atmospheres."

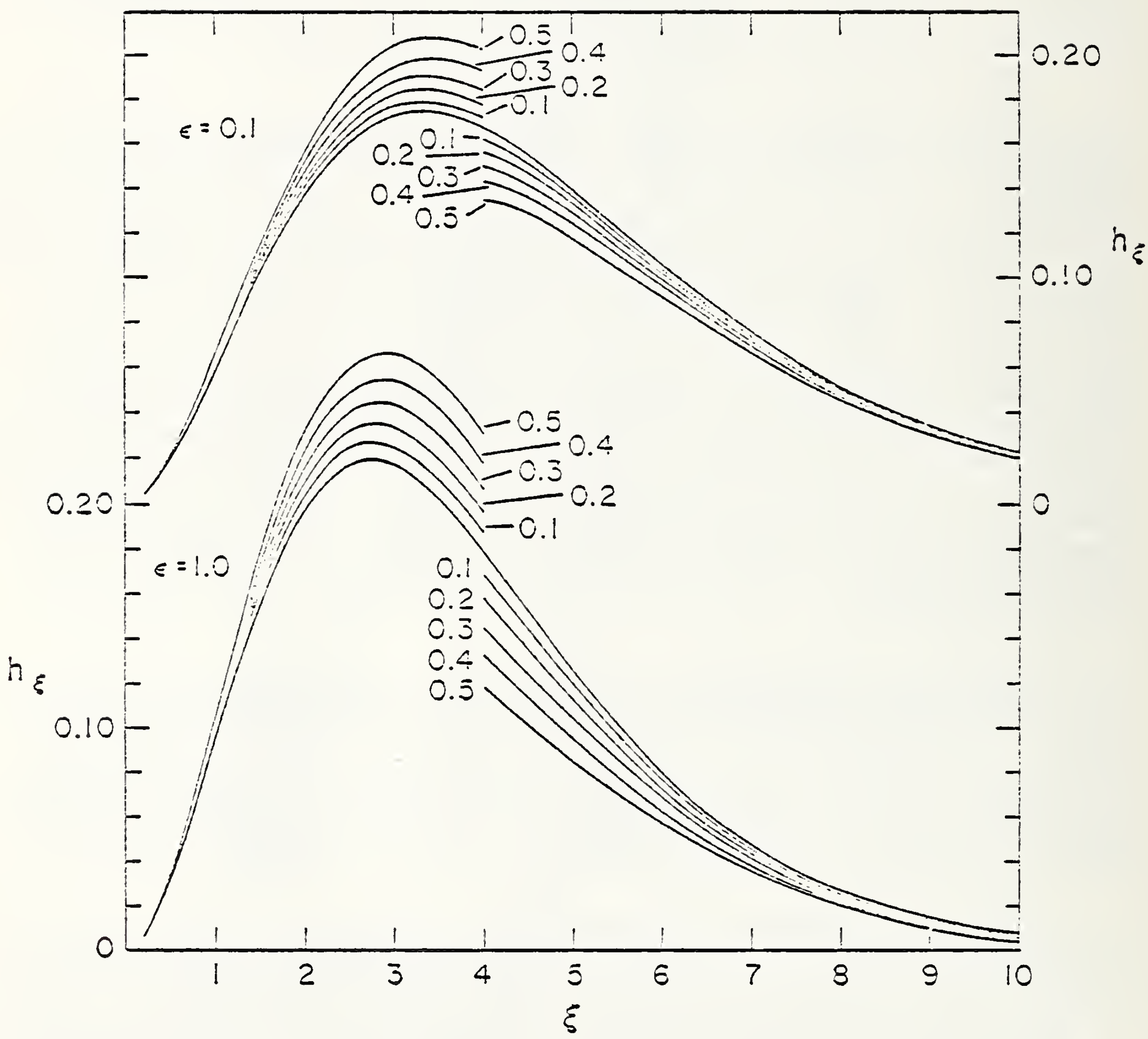



Fig. 12. The normalized flux distribution vs. $\xi = h\nu/kT_{eff}$ for a stellar atmosphere in which a fraction $\rho$ of the emerging radiation is reflected back into the atmosphere for $\xi \geq 4$, for purely absorbing ($\varepsilon = 1.0$) and primarily scattering ($\varepsilon = 0.1$) media.

Atomic and Molecular Physics and Interactions

Excitation of He-Like Ions. A. K. Pradhan, D. G. Hummer and D. W. Norcross have computed detailed and exhaustive rate coefficients for electron-impact excitation of seven helium-like ions from Be III to Fe XXV. These calculations involved the ten possible transitions involving the ground and n=2 excited states, and included the effects of resonances in Rydberg series converging on both the n=2 and n=3 levels of the ions. These were found to significantly enhance the rate coefficients for most of the transitions. Typical results are shown in Fig. 13.

These new rate coefficients were then used by A. K. Pradhan and J. M. Shull to produce improved values of the ratios of spectral lines that are routinely used as diagnostics of temperature and electron density in high temperature plasmas. The comparison with earlier results shown in Fig. 14 is typical. The accuracy of the present results is supported by solar observations, for which the temperature can be independently estimated.

The next stage of this study involves evaluation of the effect of dielectronic recombination on the excitation cross sections and rate coefficients. A. K. Pradhan has shown that this effect may significantly reduce the enhancement of the effective contribution due to resonances found earlier, and that this process is likely to be of importance in analyzing line emission from high temperature plasmas. The effect on the excitation cross section contributing most directly to the ratio G of Fig. 14 is shown in Fig. 15. A similar sequence of calculations on magnesium-like ions is in progress.

R. Christensen and D. W. Norcross have completed a more elaborate set of calculations for $Li^+$ in order to explore sensitivity to specification of the target wave function, and to test the techniques used to include resonance structure, in the more extensive calculations for the helium-like ions. This ion is particularly interesting, as it is the only case for which a spin-forbidden transition has been measured (by W. T. Rogers, J. O. Olsen and G. H. Dunn), and the only simple ion for which resonance structure has been observed. The results of these calculations are shown in Fig. 16. Agreement with the measured data is remarkably good, and provides a partial identification of the resonant feature at ~66 eV as an excitation of a combination of the 1s3s3p $^2P^0$ and $1s3p^2$ $^2D$ states of lithium.

Electron Collisions with Polar Molecules. N. T. Padial and D. W. Norcross are continuing to study aspects of electron collisions with polar molecules. Recent advances in formal aspects include: the derivation of a new sum rule for Clebsch-Gordan coefficients; generalization of the expression relating body-frame (fixed-nuclei) and laboratory-frame cross sections for linear and symmetric-top molecules to asymmetric-top molecules, and the demonstration that for this case also the cross section

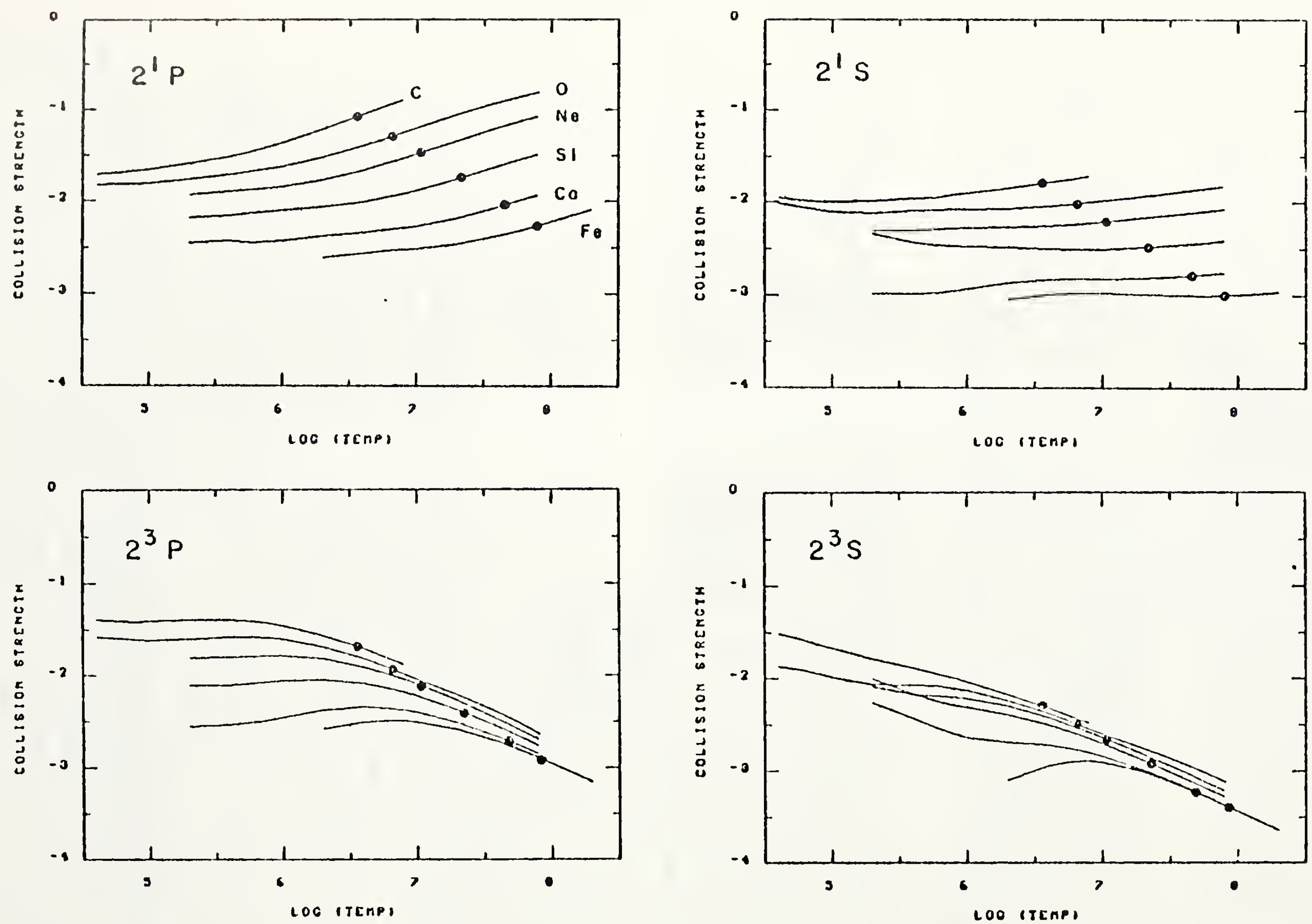



Fig. 13. The $\log_{10}$ of the Maxwellian-averaged collision strength (cross section × collision energy) for four He-like levels excited from the ground ($1^1S$) state. The filled circles mark the temperature corresponding to the ionization energy of the species, for convenience in isoelectronic sequence extrapolation.

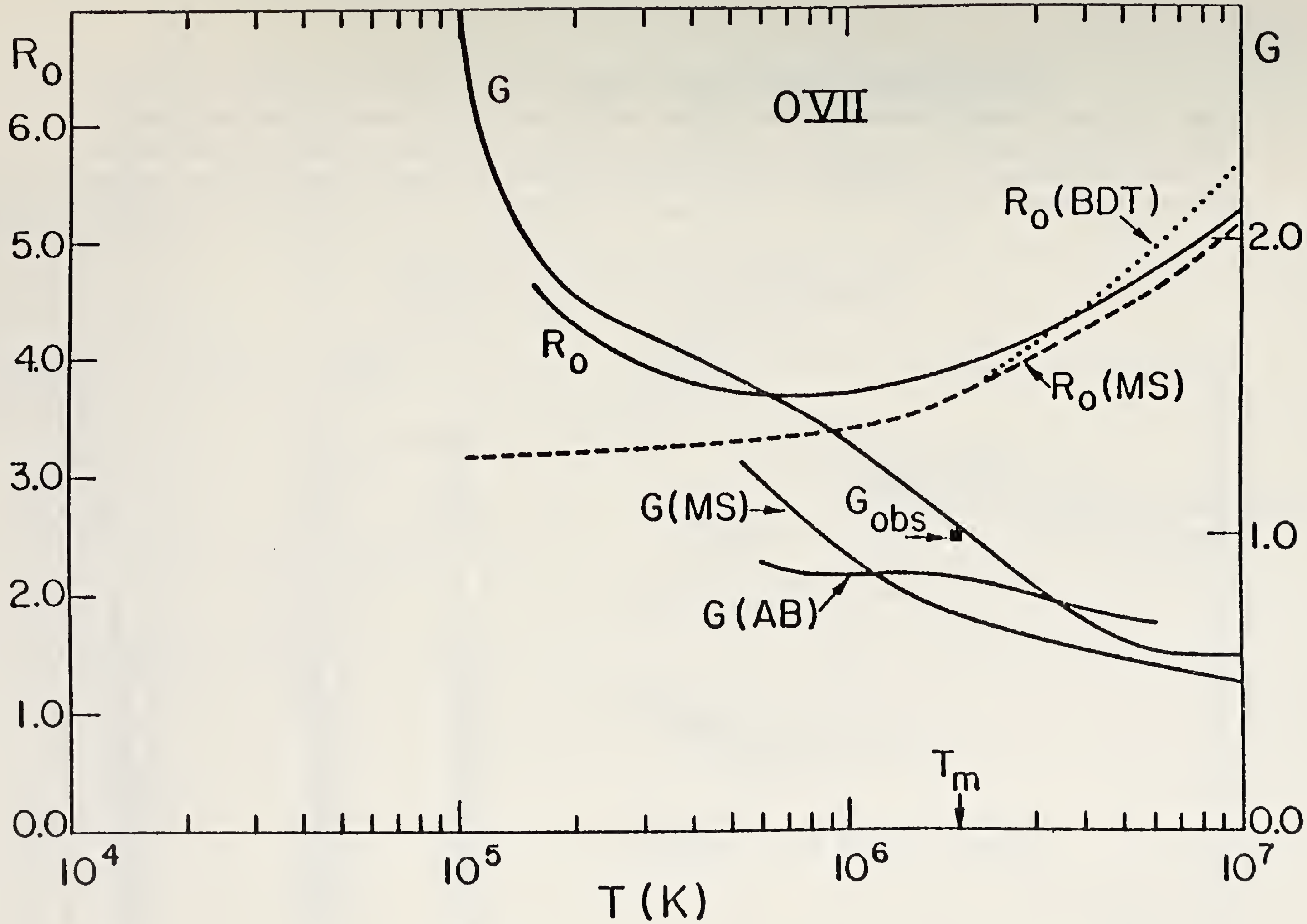



Fig. 14. Line ratios G(T) and $R_0(T)$ for O VII, as computed in this work and by others (BDT, MS, AB). $G_{obs}$ is the ratio observed in the sun (Acton and Catura 1976) at the temperature $T_m$ of maximum emission.

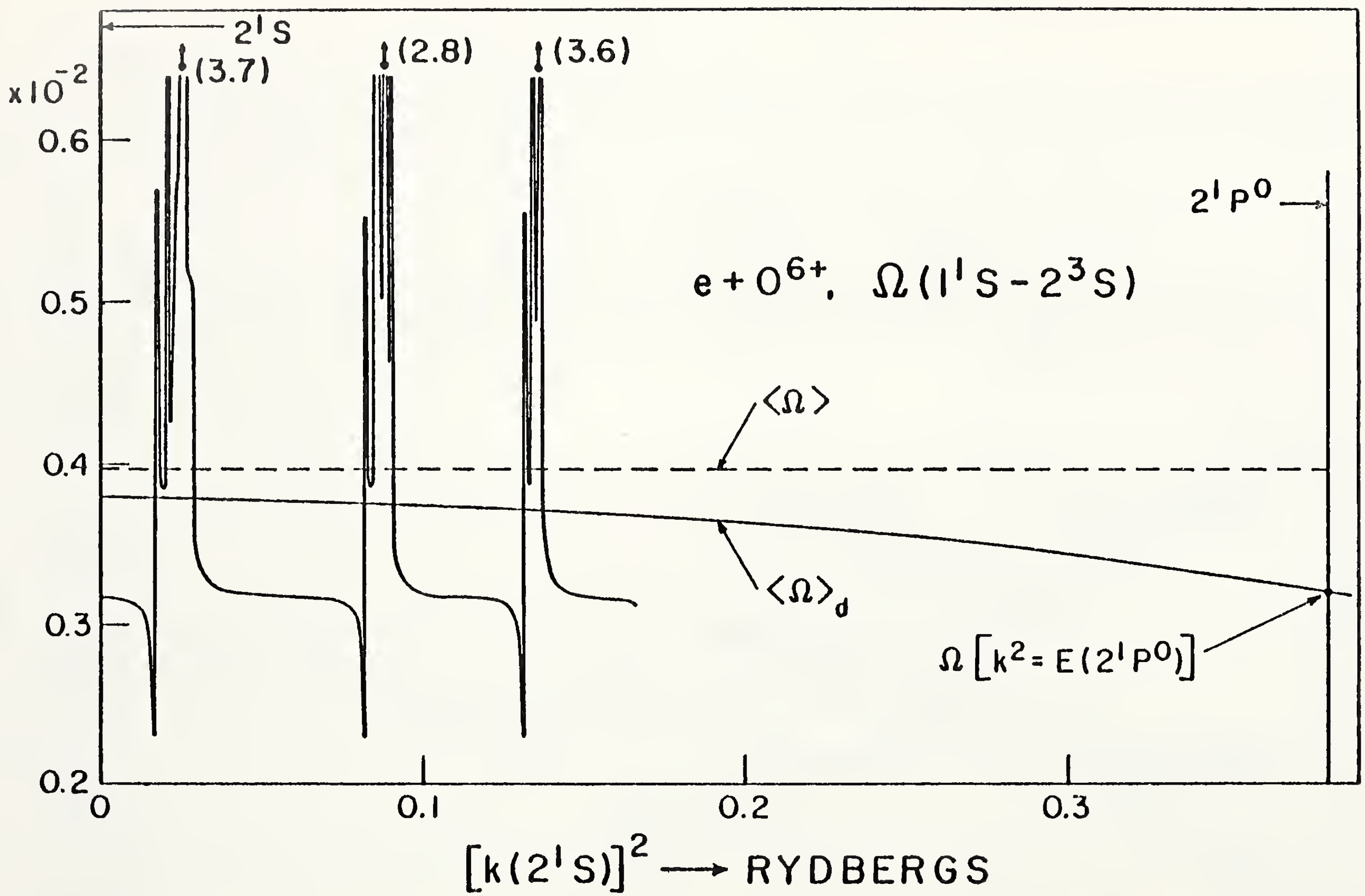



Fig. 15. Collision strengths for excitation of the $2^3S$ state of O VII from the ground state in the energy range between the $2^1S$ and $2^1P$ states. The smooth curves represent averages over the resonance structure. The difference between the dashed and solid curve represents the effect of resonance enhancement of the collision strength being lost through dielectronic recombination.

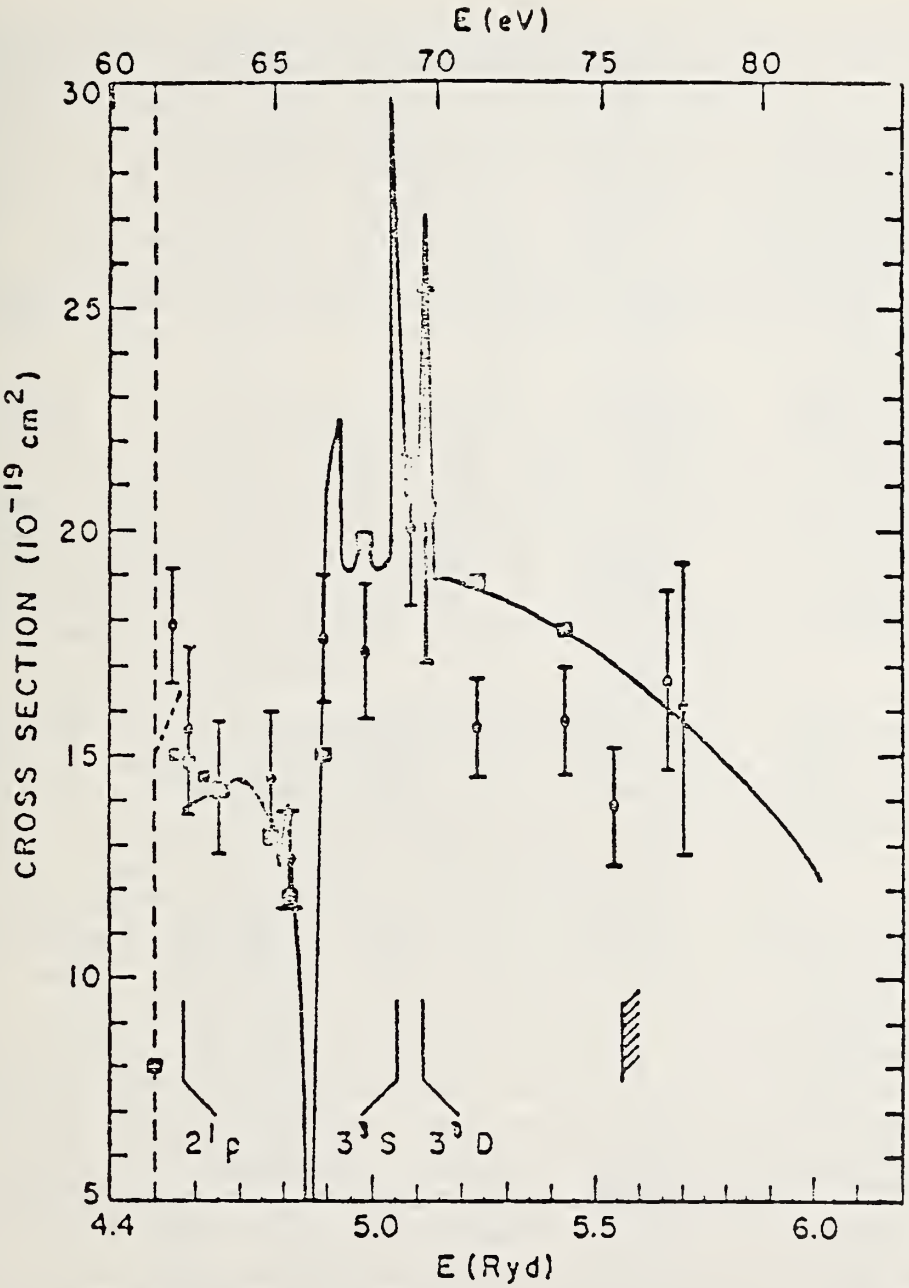



Fig. 16. Cross section for excitation of the $2^3P$ state of $Li^+$ from the ground state. The solid and dashed curves are the results of the present work, the latter being an average over the Rydberg series of resonances converging on the $2^1P$ state. The points mark the measured results (Rogers, Olsen and Dunn 1978), and the squares the present results folded with the experimental energy resolution.

for transitions between any rotational states can be written as a simple linear combination of those for the ground rotational state; and the derivation of a general expression for the energy-loss, or stopping, cross section for particles incident on all three classes of molecules, within the context of the adiabatic-nuclei approximation. They also developed an extension of this approximation appropriate to electron collisions with polar molecules, for which it ordinarily has limited applicability due to the long-range nature of the intraction. The essence of the method consists of extracting the effects of the long-range interactions from the usual body-frame (fixed-nuclei) expressions and reintroducing them in the laboratory-frame in a consistent manner.

These formal developments have been incorporated in computer programs and applied in an extensive set of calculations for $HC\ell$. One set of scattering calculations, which may be quite elaborate and expensive, can be used to generate cross sections for arbitrary initial and final rotational states. This is illustrated for the third rotational state of $HC\ell$ in Fig. 17a. Agreement of the results with measured data, over the energy range 0.3 to 11 eV, for which Fig. 17b is typical, is generally excellent. These calculations are being pushed to lower energies with the aim of exploring near-threshold vibrational excitation.

Ionization of Ions: Excitation-Autoionization. R. A. Falk and G. H. Dunn, along with collaborators at Oak Ridge National Laboratory, showed the possible dominance of excitation-autoionization in electron impact ionization of ions. Using crossed beams of ions ($Ti^{+3}$, $Zr^{+3}$, $Hf^{+3}$) and electrons, their experimental measurements shown in Fig. 18 demonstrate dramatically that excitation of an inner-shell electron to a level above the next ionization continuum, followed by autoionization (excitation-autoionization) increases the cross sections by more than an order of magnitude over that anticipated for direct ionization. Their theoretical predictions of both the energies and approximate magnitudes of these excitation cross sections provide confidence that this important indirect contribution to the total ionization can be estimated for many cases important in fusion and other hot plasmas. G. Dunn, A. Falk and D. Belić, along with ORNL collaborators also made measurements on ions in the Na isoelectronic sequence ($Mg^{+}$, $A\ell^{2+}$, $Si^{3+}$), finding several anomalies (compared with theory) in both the direct and indirect processes. The work on the Na sequence complements other work they are completing on the Be and Li sequences.

Excitation of Ions. Crossed beams of $A\ell^{+2}$ and electrons were used by Falk, Belić and Dunn to measure the cross section for the 3S-3P excitation of this Na-like ion, observing the resultant 186 nm radiation. Analysis of the data is still under way, but comparisons with theories indicate some interesting and possibly important effects. All successful measurements on ion excitation which have been made to date have used the fluorescence technique, and most have been made over the past decade by Dunn's group. However, limitations on detector sensitivity,

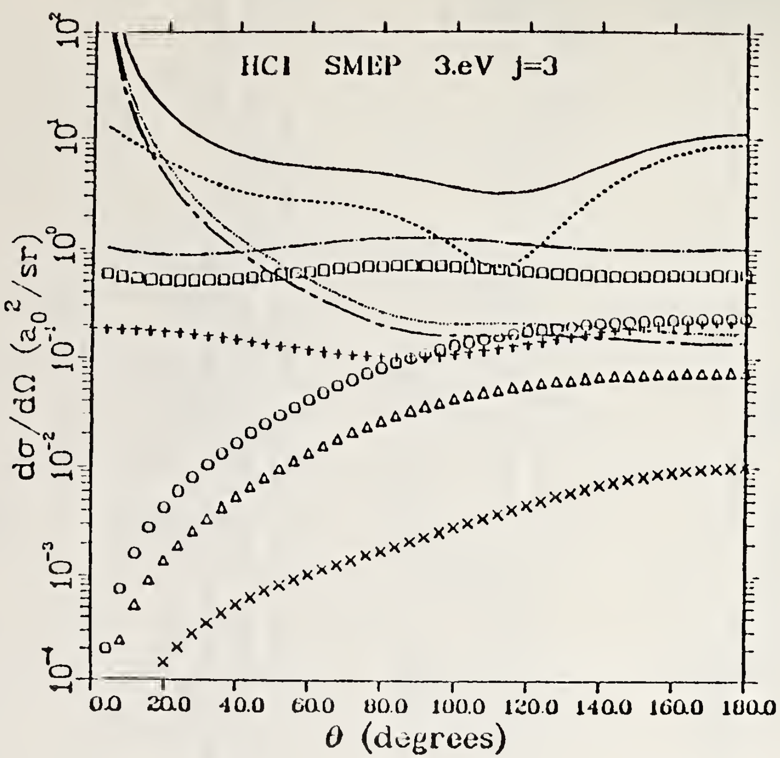



Fig. 17a. Differential cross sections for elastic scattering of electrons by HCℓ. The largest contributions to the total cross section (solid curve) are from the rotational transitions j to j' of 3-3 (- - -), 3-2 (-- - --), 3-4 (····), 3-1 (||), and 3-5 (-----·).

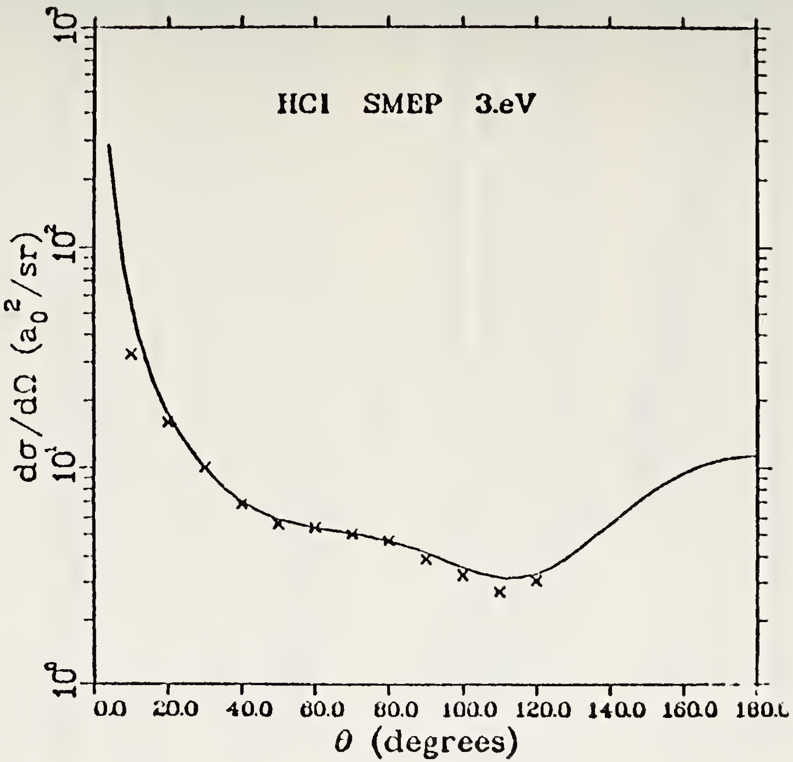



Fig. 17b. Total differential cross section for elastic scattering of electrons by HCℓ. The solid curve is the present results, the crosses mark the experimental results (Rohr and Linder, 1976), which have been normalized to the present results at 60°.

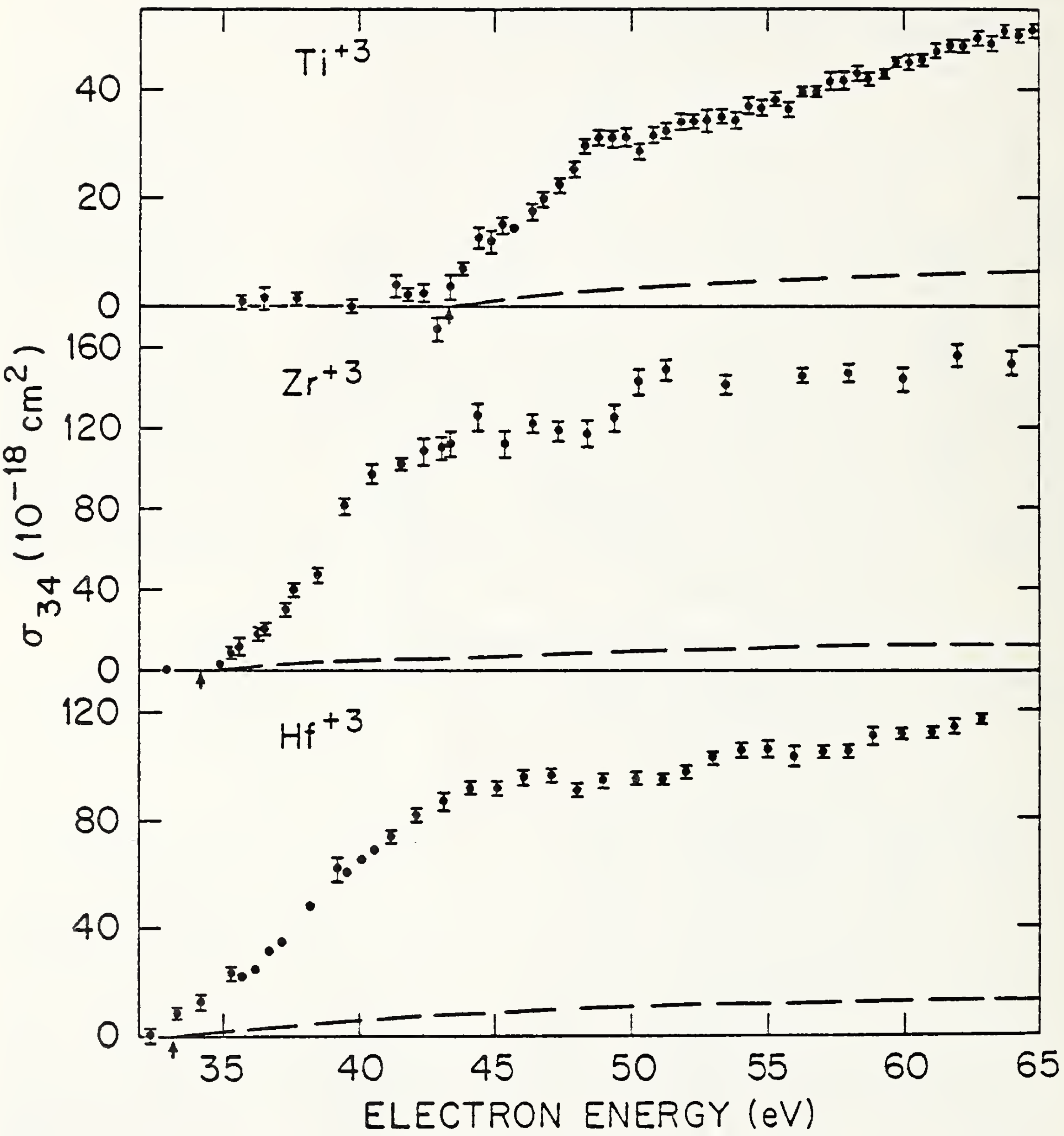



Fig. 18. Experimental results for electron-impact ionization of $Ti^{+3}$, $Zr^{+3}$, and $Hf^{+3}$. Error bars are one standard deviation of the mean statistical uncertainty. Dashed curves are calculated estimates of the direct ionization process.

wavelength dispersion, lifetimes, etc. preclude measurements on many important systems and transitions using this technique. Dunn and Belić have under design a new technique which will detect inelastically scattered electrons. A bonus of the new method may be the possibility of measuring cross sections for dielectronic recombination. It is anticipated that construction of apparatus to do this will begin this year.

Ion-Molecule Reactions Near 4 K. J. Luine and G. Dunn used their newly developed and unique ion-trap technique for measuring ion-molecule reaction rates at temperatures near 4 K to study several important processes at low temperatures. The reaction probabilities for the hydrogen abstraction reaction sequence

$$N^+ \xrightarrow{H_2} NH^+ \xrightarrow{H_2} NH_2^+ \xrightarrow{H_2} NH_3^+ \xrightarrow{H_2} NH_4^+$$

were mesaured in the 11 to 20 K temperature range, and results for the first process are shown in Fig. 19. The mesaurements have direct and important consequences in the modeling of ammonia formation in the interstellar medium. The radiative association, $C^+ + H_2 \rightarrow CH_2^+ + h\nu$, has received extensive experimental and theoretical attention recently, as it has been proposed as a critical, rate limiting step in the formation of hydrocarbon molecules in interstellar space. Luine and Dunn measured a new upper limit of $k_R < 2 \times 10^{-15}$ cm$^3$ s$^{-1}$ for the rate for this process. The limit is more than an order of magnitude less than previous measurements, and is the first at the very low temperatures characteristic of dark interstellar clouds. A stronger magnetic field (~60 T) should allow pushing the limit another order of magnitude -- to the range predicted by the most recent theories and "needed" in the models of interstellar hydrocarbon molecule formation.

Free-Free Transitions: Theoretical. The project initiated last year by S. Geltman and M. J. Conneely (visitor from the University of Galway, Ireland) on free-free transitions at electron-hydrogen atom scattering resonances has been completed. They used the electron-hydrogen atom scattering wave functions in the 1s-2s-2p close-coupling approximation to evaluate the appropriate free-free dipole matrix elements. They studied the differential cross sections associated with the absorption of $CO_2$ laser radiation (0.117 eV) for electrons whose initial or final scattering energies coincided with one of the Feshbach resonances below the n=2 threshold, as well as free-free transitions between two Feshbach resonances. For higher photon energies, say those from a Nd laser (1.17 eV), a free-free transition originating in a Feshbach resonance below n=2 may also produce the simultaneous excitation of the hydrogen atom to the 2s and 2p states. The differential cross sections for these processes were studied and the forward scattering result is shown in Fig. 20. The two peaks in each curve are due to the $2s^2\ ^1S$ and $2s2p\ ^3P$ scattering resonances. The latter resonance is seen to give enhancements of $\sim 10^3$ over the nonresonant background. There is as yet very little experimental data, and none involving hydrogen atoms, on these processes, and it is hoped that the present results will help stimulate such measurements.

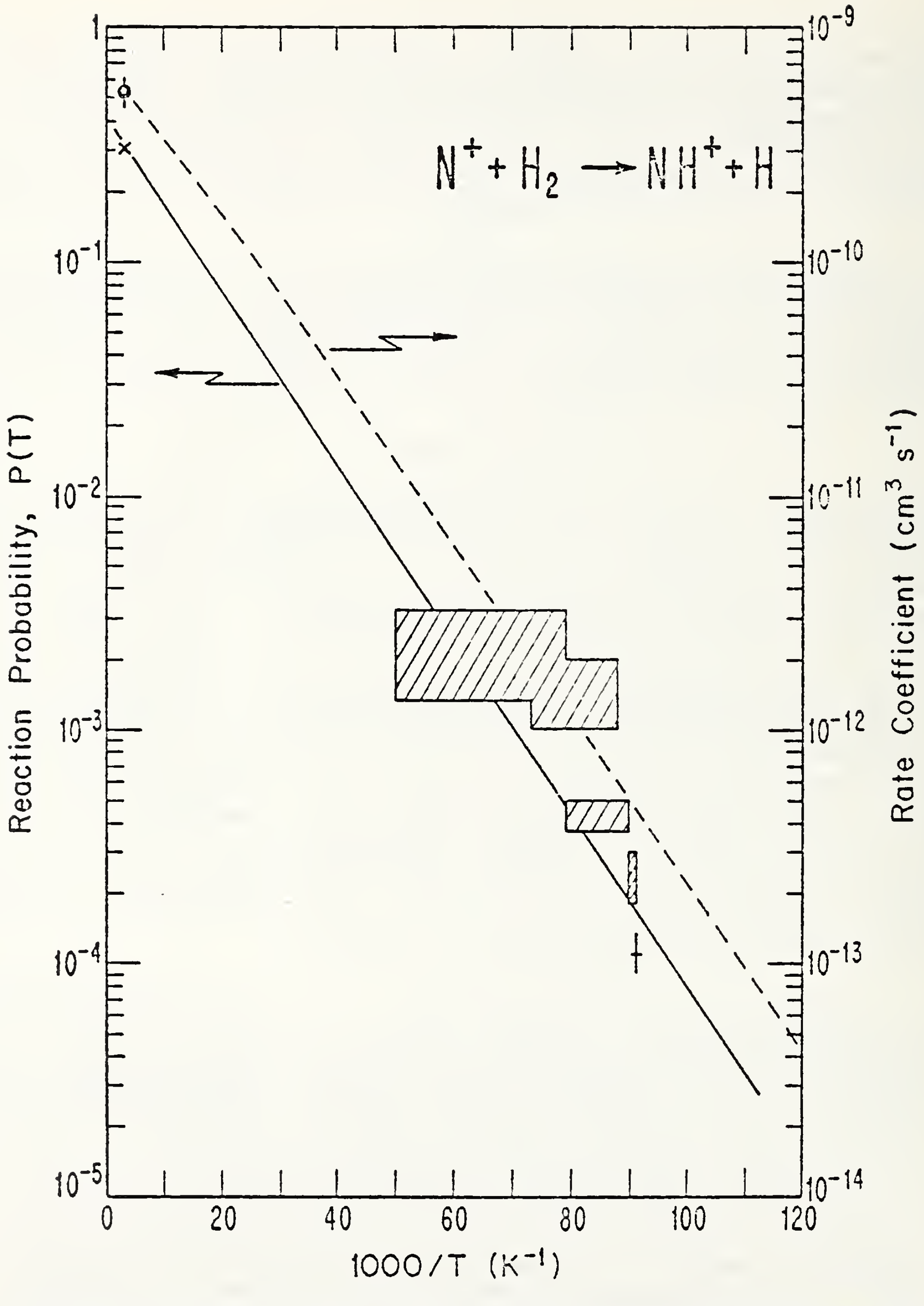



Fig. 19. Standard Arhenius plot. Solid curve represents the expression $P(T) = (0.41 \pm 0.1)\ e^{-(85 \pm 10)/T}$ deduced as the reaction probability for the process $N^+ + H_2 \rightarrow NH^+ + H$ from present measurements. The dashed curve represents the rate coefficient from these measurements, $k(T) = 1.28 \times 10^{-9}\ (T^{-1/6} + 0.117)\ e^{-85/T}\ cm^3\ s^{-1}$.

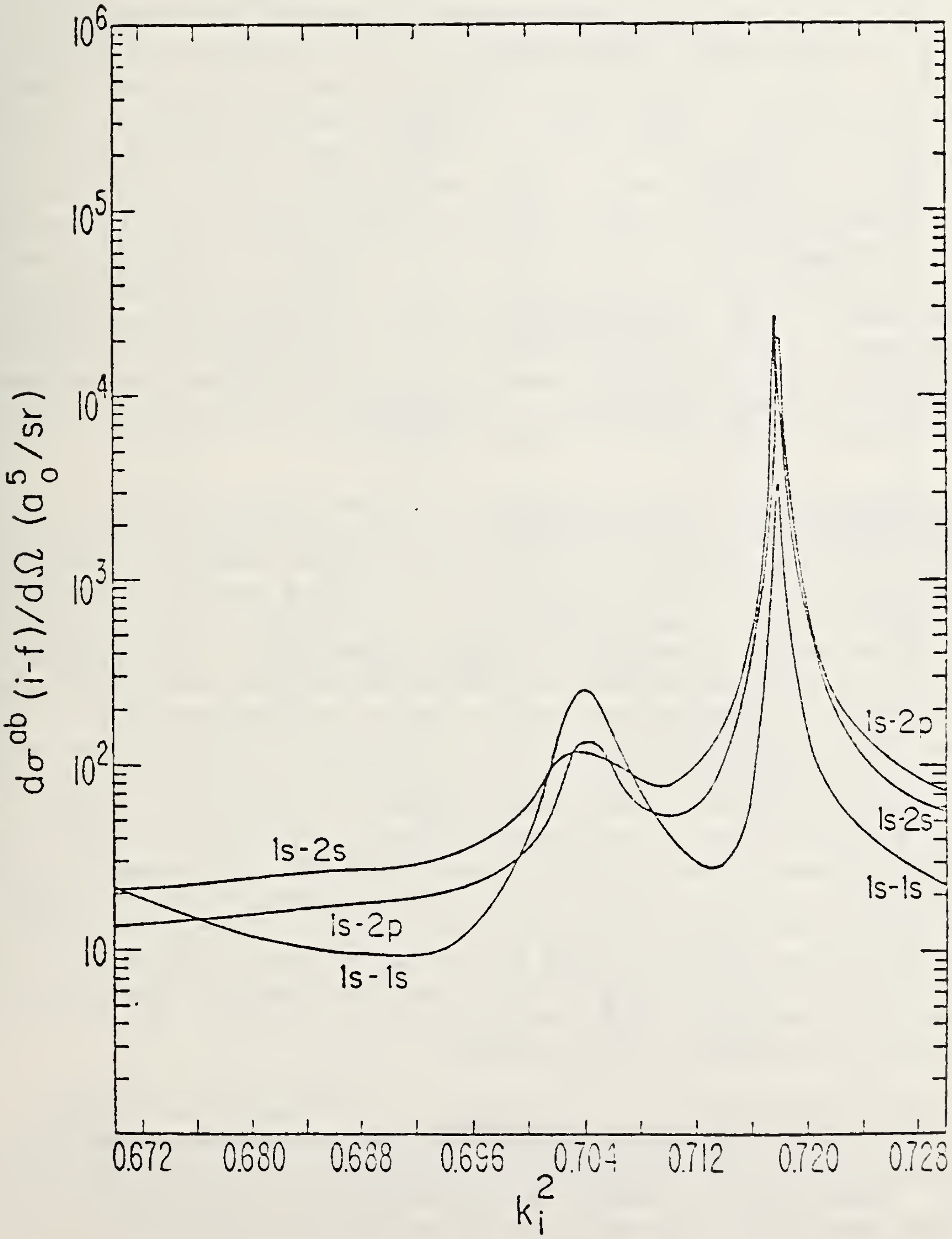



Fig. 20. Differential free-free cross sections per unit electron density in the forward direction for the absorption of a 1.17 eV photon as a function of the initial electron energy $k_i^2$(Ryd).

Free-Free Radiation: Experiments. A. V. Phelps, in collaboration with Dr. C. Yamabe of Nagoya University, has succeeded in mesauring the absolute intensity of free-free radiation or bremsstrahlung produced in the collisions of free electrons with argon atoms using the electron drift tube technique. This measurement is particularly noteworthy because of the very small cross section for IR or visible photon production, i.e., about $10^{-26}$ $m^2$, the very small power density input used in the drift tube, i.e., $\sim 10^{-12}$ $W/m^3$, and the ease with which the electron energy can be varied. Most previous measurements have been made using shock tubes or electric arcs. These measurements are a significant advance in that they yield quantitative values of the rates of free-free emission for comparison with theory, such as that of S. Geltman, and for use in the quantitative diagnostics of high pressure, weakly ionized plasmas, such as the ionosphere, discharge lasers and charged particle beam plasmas. Preliminary results of these measurements for electrons in argon are shown in Fig. 21, where the excitation coefficient appropriate to drift tube experiments is compared to the results of a calculation based on one of the simpler theories.

Electrons in $N_2$. A. V. Phelps, in collaboration with L. C. Pitchford of Sandia National Laboratories, has extended the calculation of the electron energy distribution functions and transport coefficients for electrons in $N_2$ to high electric field to gas density ratios E/N, where anisotropies in the electron collisions with $N_2$ molecules and in the electron energy distribution become appreciable. This project included an analysis of the available experimental and theoretical elastic and inelastic scattering cross section data for electrons by $N_2$ so as to express the data as energy dependent coefficients of a spherical harmonic expansion. Figure 22 shows a portion of the results of this analysis for elastically scattered electrons between 0.1 and $10^4$ eV. These results and the previously developed techniques for the solution of the electron Boltzmann equation make possible for the first time a meaningful calculation of the effects of anisotropic scattering on electron transport and reaction coefficients at high E/N. The results of these calculations show that to a good approximation the transport and reaction coefficients depend only on the momentum transfer cross sections and the total inelastic cross sections and not on other details of the differential scattering cross sections.

Oxygen Dissociation. A. V. Phelps, in collaboration with M. A. Islam, has reactivated an experiment designed to yield rate coefficients and cross sections for the dissociation of oxygen molecules by electron impact. These data are needed for the modeling of electrical discharges for ozone production, charged particle beam systems, and switching devices. The initial phase of the project is the development of a well characterized source of oxygen resonance radiation, e.g., the control of the oxygen concentration through the use of a silver leak to admit small amounts of oxygen into the resonance lamp.

Effects of Fluctuations on Nonlinear Processes in Atoms. As the first step in an experimental study directed to providing benchmark data

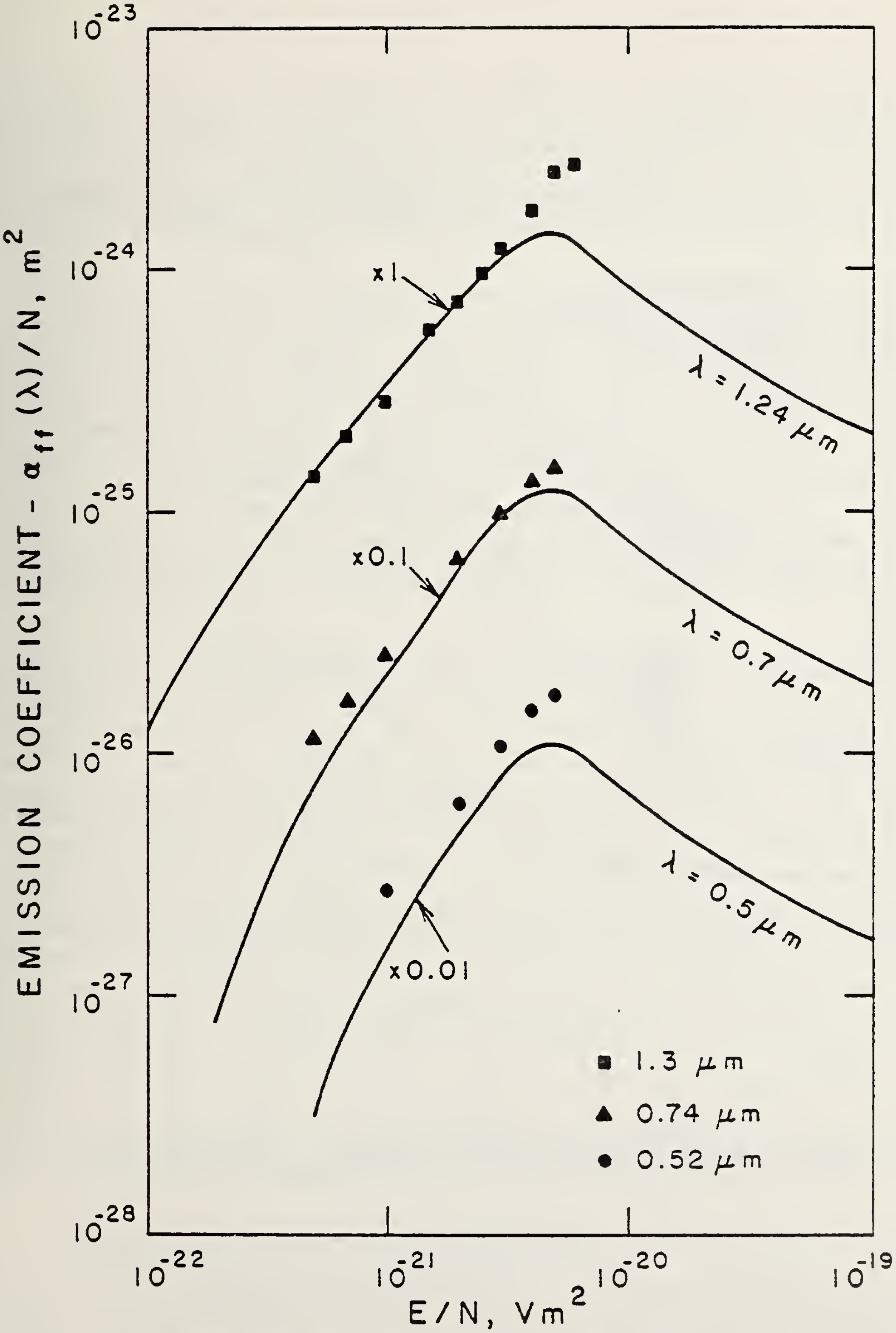



Fig. 21. Free-free emission from argon vs. electric field to gas density ratios for various wavelengths.

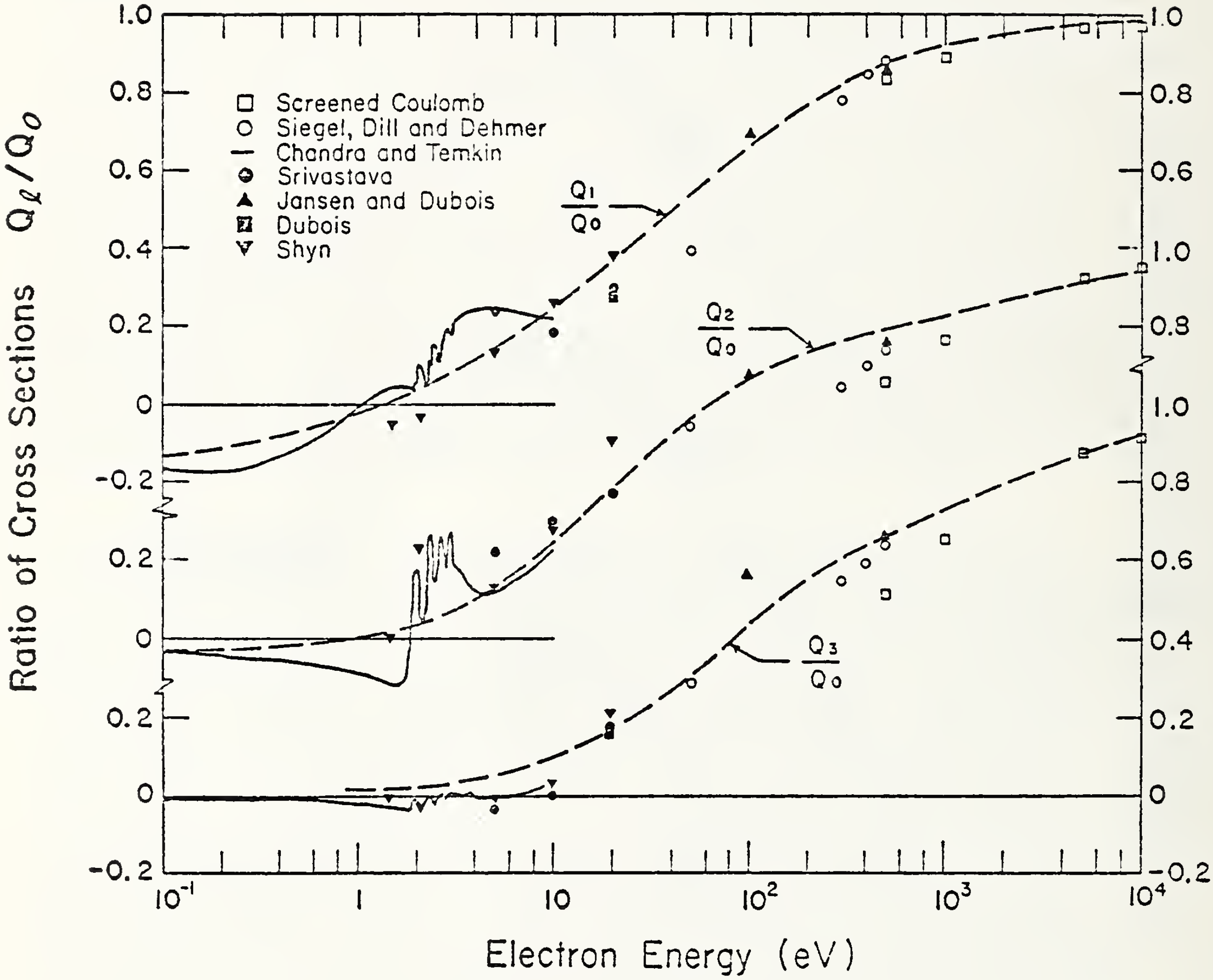



Fig. 22. Ratios of spherical harmonic components from elastic differential scattering cross section data for electrons on $N_2$.

for theoreticians investigating the effects of fluctuations on nonlinear processes in atoms, D. Elliott, R. Roy and S. J. Smith have developed a method of controlling the bandwidth and bandshape of a single mode laser power spectrum by superimposing freqency fluctuations onto the laser beam. This process is external to the laser cavity, and the method is applicable to a laser beam with no modifications to the laser.

The major components used for superimposing frequency fluctuations on the laser are a noise module (NM), voltage controlled oscillator (VCO) and an acousto-optic modulator (AOM). The VCO transforms the Gaussian voltage fluctuations of the NM into frequency fluctuations, yielding a constant amplitude, frequency-modulated RF signal. The acousto-optic modulator then effectively adds the RF frequency to the laser frequency, resulting in a broadened laser power spectrum. The width of this power spectrum is controlled by changing the rms amplitude of the output of the NM, and the "slew rate" of the frequency fluctuations is controlled by changing the cut-off frequency of the output of the NM. The shape of RF power spectrum is strongly dependent on the power spectrum of the white noise with which the VCO is frequency modulated.

Figure 23 shows an example of the RF power spectrum of the VCO output. Figure 23b is a logarithmic display and 23c a square-root display which result from frequency modulation derived from the white noise power spectrum shown in Fig. 23a. The central portion of the RF power spectrum is nearly Lorentzian, with a Gaussian character dominating the wings. The crossover frequency between these two shapes is the cut-off frequency of the white noise spectrum. Improvements under consideration include a method of increasing the white-noise cut-off frequency limit, and of obtaining an acousto-optic modulator with a wider and more symmetric response than the one which we are currently using. The system is operational, and the study of the atom-fluctuating laser interaction problem is being implemented. Bandwidth and bandshape control of the laser power spectrum is attractive for a variety of other reasons. For an inhomogeneously broadened transition in a sample of atoms or molecules, instead of saturating the transition for only one subgroup, the laser spectrum can be broadened to be in resonance with all the atoms or molecules in the sample. In the study of laser-atom interactions which do not involve the hyperfine structure of the atom, the laser spectrum can be made broader than the hyperfine splitting, eliminating effects due to this atomic structure.

Photoionization of Excited State Atoms. Studies of photoionization out of highly excited and aligned states of atomic sodium have been carried out by G. Leuchs (Visiting Fellow), D. Elliott, R. Roy, and S. J. Smith. These are among the first studies of photoionization out of levels higher than n=10 and are the first such to include careful measurement and analysis of photoelectron angular distributions. Atoms are resonantly excited by linearly polarized pulses from two nitrogen pumped dye lasers, one tuned to a component of the resonance line and the second to the appropriate 3P→nD or 3P→nS transition. Photoionization is accomplished with a 12 nsec pulse at 1.06 μm generated by a YAG

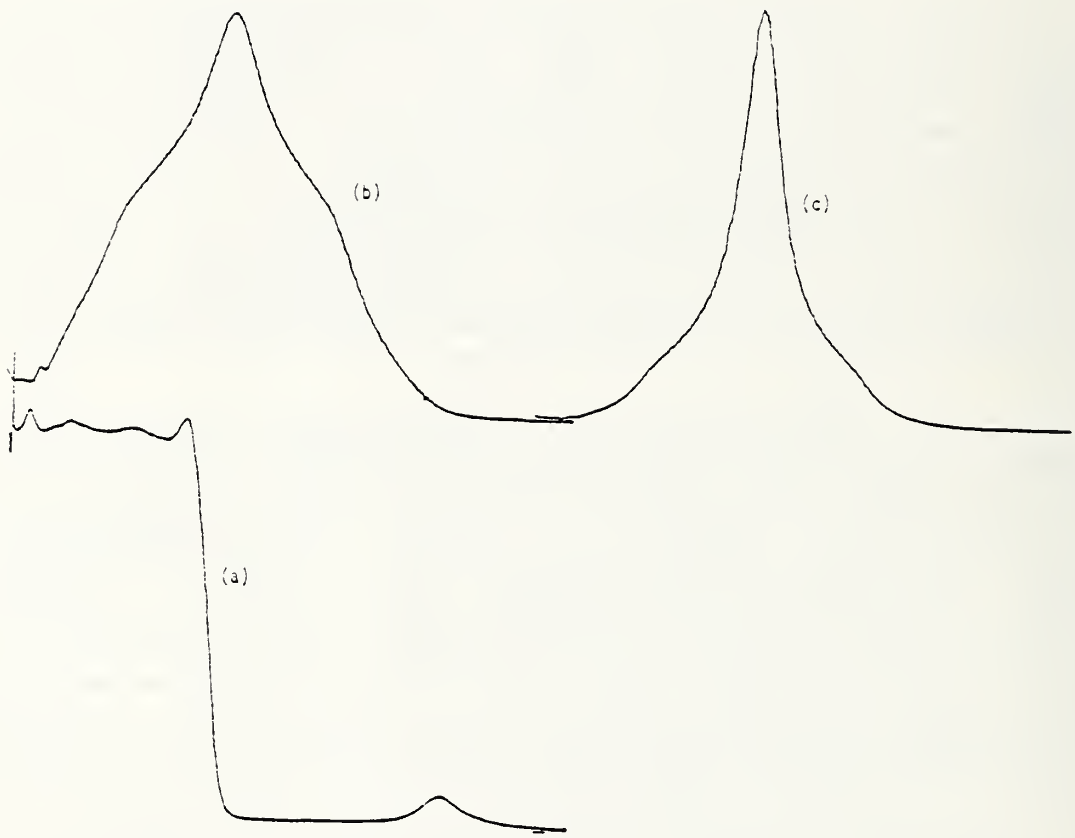



Fig. 23. A white (Gaussian) noise spectrum cut-off at 90 MHz (a) produces the F.M. power spectra shown in (b) (logarithmic ordinate) and (c) (square-root ordinate) for use in controlling the bandwidth of a laser by means of an acousto-optic modulator. The shoulders on (b) and (c) occur ~90 MHz from the central frequency. The inner portion is Lorentzian in character while the wings are Gaussian.

oscillator and amplifier system. Delayed field ionization is used to monitor upper state populations. Angular distributions are measured by using a fixed position detector and rotating the plane of linear polarization with a $\lambda/2$ plate.

Figure 24 shows curves of the form

$$I(\theta) = \sum_n a_n \cos^{2n}\theta \quad ,$$

fit to experimental points (x) for photoionization from aligned 20D states of sodium. Alignment derives from excitation with parallel linear polarizations. Photoionization with the linear polarization of the 1.06 $\mu$m radiation set orthogonal to the exciting radiation yields the butterfly pattern shown on the right. Parallel polarization yields the left-hand pattern. Analysis of such parallel patterns, for the analogous process but through the $3P_{1/2}$ state, shows that at n=20 a $\cos^6\theta$ component is present, in apparent violation of the dipole approximation. This is consistent with the fact that the optical phase ($\vec{K}\cdot\vec{r}$) variation across the radial dimension of the n=20 orbital is ~0.2 (for a hydrogenic orbital) and the dipole approximation should begin to fail. Measurements at n=25, 30 and 35 emphasize that by n=30 and 35 the failure seems complete.

In contradiction to this interpretation, however, recent theoretical calculations (Dixit and Lambropoulos, private communication; and Christensen-Dalsgaard, private communication) show that quadrupole contributions, even if present, should not appear at the angle of observation used in the measurements. Possible contributions by higher order poles or by such terms as might be due to dipole-octopole interference have not yet been examined theoretically. Finite collection angles could permit observation of small quadrupole contributions, but probably not as large as were observed. Electric field mixing estimates seem to preclude mixing as a source of error. An additional possibility requiring further investigation is the pickup of additional photons by the outgoing electron, in the extremely intense (~$10^{10}$ watts/cm$^2$) ionizing laser field. This would modify angular distributions.

At these intensities three-photon nonresonant ionization out of the 3P state, and five-photon nonresonant ionization out of the ground state are also observed and are found to require significant corrections to the n=25 and n=30 results respectively.

Heavy Symmetry Molecules. F. Pipkin (Visiting Fellow), R. Roy, D. Elliott and S. J. Smith are continuing with the development of a stimulated Raman gain experiment, using a unique high-intensity narrowband pulsed laser system, to examine rotational spectra of heavy symmetric molecules in a search for the "spectral clustering" predicted by former Visiting Fellow W. Harter on the basis of higher symmetries of these molecules.

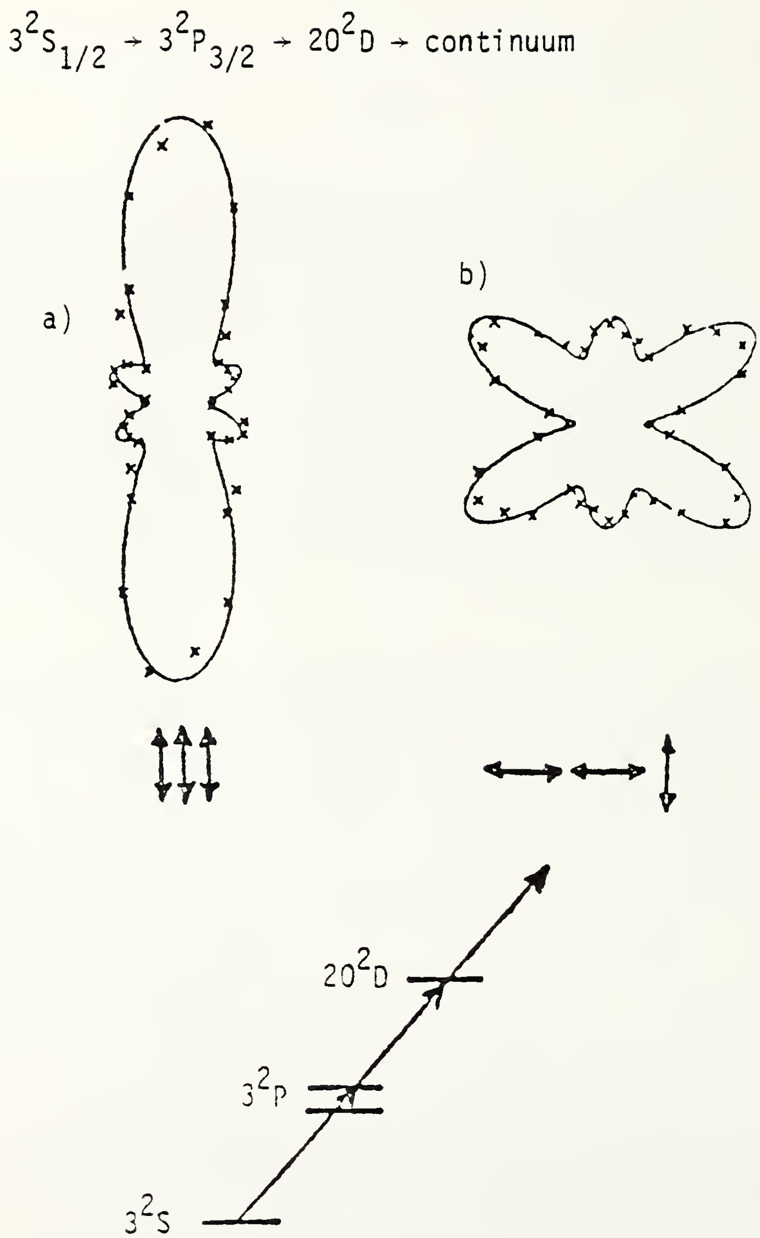



Fig. 24. Measured angular distributions (×) of photoelectrons from the $20^2D$ excited state of atomic sodium, aligned by stepwise excitation to $20^2D$ with parallel linearly polarized pulsed lasers. The two patterns result from orienting the linear polarization of the photoionizing laser beam a) parallel and b) perpendicular to the axis of alignment. The solid curves represent fits of expansions in $\cos^2\theta$, where $\theta$ is measured with respect to the axis of alignment.

Long Range Atom-Atom Interactions. W. Kamke, B. Kamke, and A. Gallagher are continuing their studies of mixed-alkali interactions, which are of particular interest as diagnostics of collisional line-shape theories. They have been measuring the collisional broadening of the Na resonance lines by Rb. Combined with previous measurements of the line wings in FY 79 this provides detailed insights into these exceptionally long-range atom-atom interactions. They have also obtained preliminary measurements of the extreme-wing intensities of the Na resonance lines due to perturbation by $N_2$. This radiation is due to the Na-$N_2$ triatomic collision complex, so that its interpretation is much more complex than the atom-atom case and much more data and theory are needed to build a detailed understanding of the process. This problem is directly analogous to observing the interaction surfaces in chemical reactions, so that extensive measurements and diagnostics over an extended period are planned.

J. Huennekens and A. Gallagher, as part of their study of high-density Na vapor in strong laser fields, have measured the collisional absorption in the wings of the $D_1$ and $D_2$ resonance lines. This absorption, due to the Na-Na resonance interaction, is observed in this optically thick vapor by measuring the Rayleigh scattering at the laser frequency and the fluorescence at the atomic frequencies. The $3P_{3/2} \leftrightarrow 3P_{1/2}$ excitation transfer cross section has been obtained at the same time from the ratio of $D_1$ to $D_2$ lines, with the Rayleigh light separated out, and a complementary measurement of the radiative decay rate for the trapped radiation. Preliminary data have also been taken on cross sections for collisions between two excited sodium atoms; these measurements will be continued in FY 82.

Electron Collisions with Excited State Atoms. R. Dang and A. Gallagher have measured the cross section for electron collisional excitation of Na(3P) atoms to the 3D state (Na(3P) + e → Na(3D) + e). Results are shown in Fig. 25. Additional measurements in the threshold energy region are planned, as are measurements of the polarization of the 3D decay radiation.

Atomic Processes in Silane Discharges. H. Chatham, R. Robertson, and A. Gallagher have studied the ion and neutral species arriving at the surface of electric discharges in silane gas, of the types used in the production of amorphous silicon solar cells. As an example, the ion species from rf, dc, and dc-proximity discharges are shown in Fig. 26. Qualitative models have been developed for the plasma processes leading to these constituents from the initial $SiH_4$, and these models are being compared to the data in an iterative manner to improve understanding of the discharge chemistry. Many of the reaction rate-coefficients needed in the models are unknown or poorly known, and an apparatus has been constructed to measure some of the ion-molecule rate coefficients.

Multiphoton Ionization. S. Haan and S. Geltman have completed their theoretical study of the time development of the resonant (3s-3p) three-photon ionization of Na with linearly polarized monochromatic

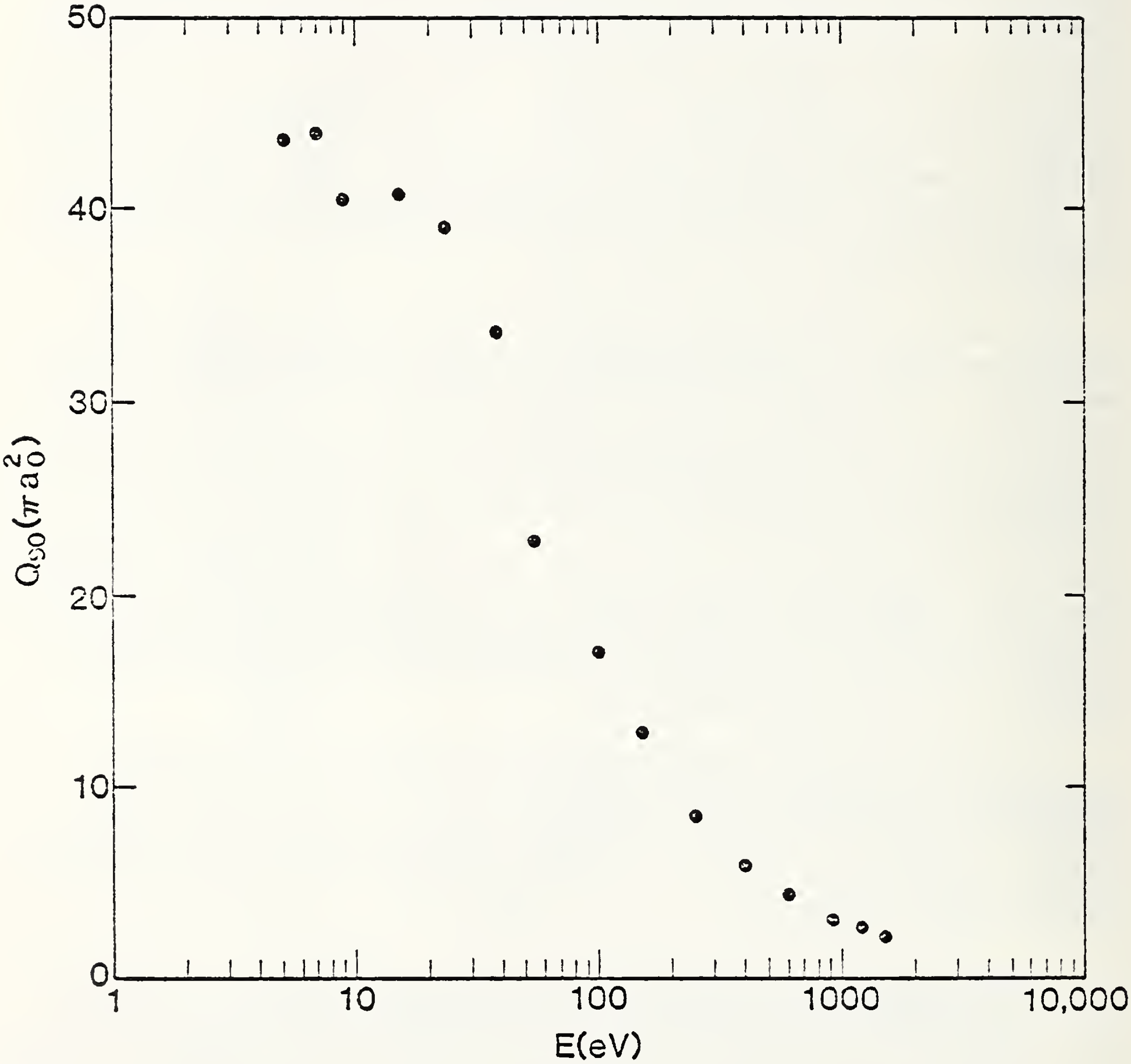



Fig. 25. Cross section for electron excitation of Na(3P) atoms to the 3D state. A polarization correction, so far unknown, must be applied to obtain the total cross section.

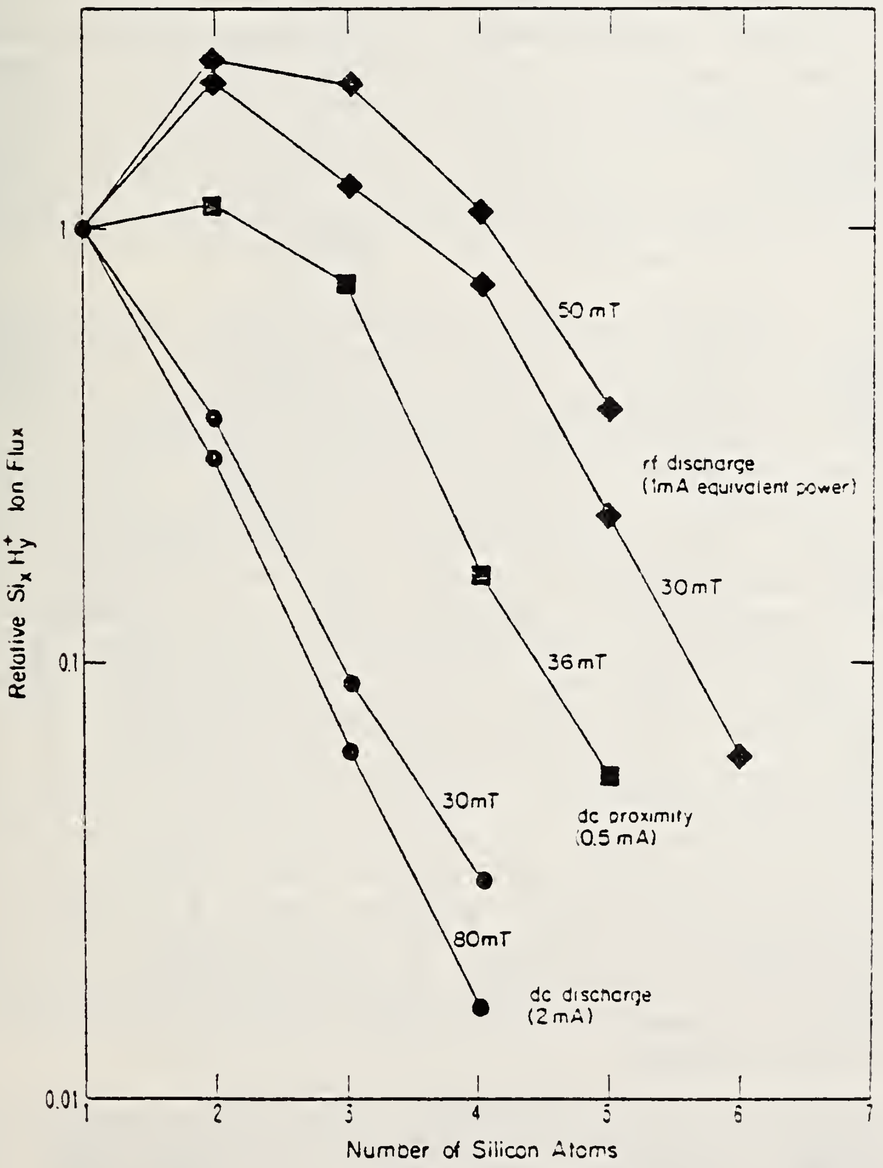



Fig. 26. Ratios of $Si_xH_y^+$ ion fluxes from three types of low-power discharges in silane. Silane pressures in mTorr are indicated.

radiation. The theoretical method they have used is to take the strongly-coupled 3s-3p rotating-wave-approximation as the lowest order solution, and to apply second order perturbation theory to obtain the ionization probabilities. The photoelectron energy spectrum and total ionization probability have been studied for various laser detunings and turn-on forms. Processes which are forbidden at long times by the energy conservation condition for monochromatic photons are found to be important at short times ($t \lesssim 10^{-9}$ s for laser intensities of order $MW/cm^2$) because of the transient photon distribution associated with the turn-on of the laser pulse. The ionization probability is found to exhibit plateau-like behavior at times much less than the 3s-3p Rabi period, and subsequently to oscillate with the 3p population before reaching rate behavior in the long-time limit. The use of the limiting rate to predict very short-time ionization probabilities gives results which can be too low by several orders of magnitude for $t < 10^{-9}$ s.

Geltman, in cooperation with D. Normand of Saclay, is in the process of completing a theoretical study of the two-photon ionization of Cs in the region of the interference minimum (near the $7p_{1/2}$ state). Additional recent experimental work at Saclay (D. Normand and J. Morellec, J. Phys. B 14, L401 (1981)) has yielded more precise values for the magnitudes of the cross section in the region of the minimum as well as the ratio of cross sections due to linearly and circularly polarized light. Their calculation to date takes complete account of all the discrete intermediate $np_{1/2}$ and $np_{3/2}$ states. The agreement with the location and magnitude of the mesaured result for linearly polarized light is quite good: within 70 $cm^{-1}$ for the position of the minimum and within the error bars of the measured magnitude $(6\pm2) \times 10^{-51}$ $cm^4$ s. For the ratio of cross sections with the two light polarizations the agreement is also quite good and is shown in Fig. 27. The theory shows quite explicitly that the ratio $\sigma_{2C}/\sigma_{2L}$ has a maximum value of 3/2 in the vicinity of the interference minimum, and this is very well confirmed by the experimental points. All that remains to be done in this study is to calculate the contribution of continuum intermediate states, and this is not expected to be large. The present theoretical results are in much closer agreement with experiment than other theoretical calculations in the literature.

Laser-Induced Collisional Ionization. Work on the theory of laser-induced collisional ionization is being continued by S. Geltman. Some progress has been made on understanding the measurements made on the process

$$Sr(5p\,^1P) + Cs(6s\,^2S) + \hbar\omega \rightarrow Sr(5s\,^1S) + Cs^+ + e$$

by Brechignac et al., J. Phys. B 13, L383 (1980). A separated-atom approach in which the Sr 5s-5p Rabi oscillation serves as the basis of a perturbation treatment of the atom-atom interaction gives a satisfactory explanation of the spectral width which was observed as a function of

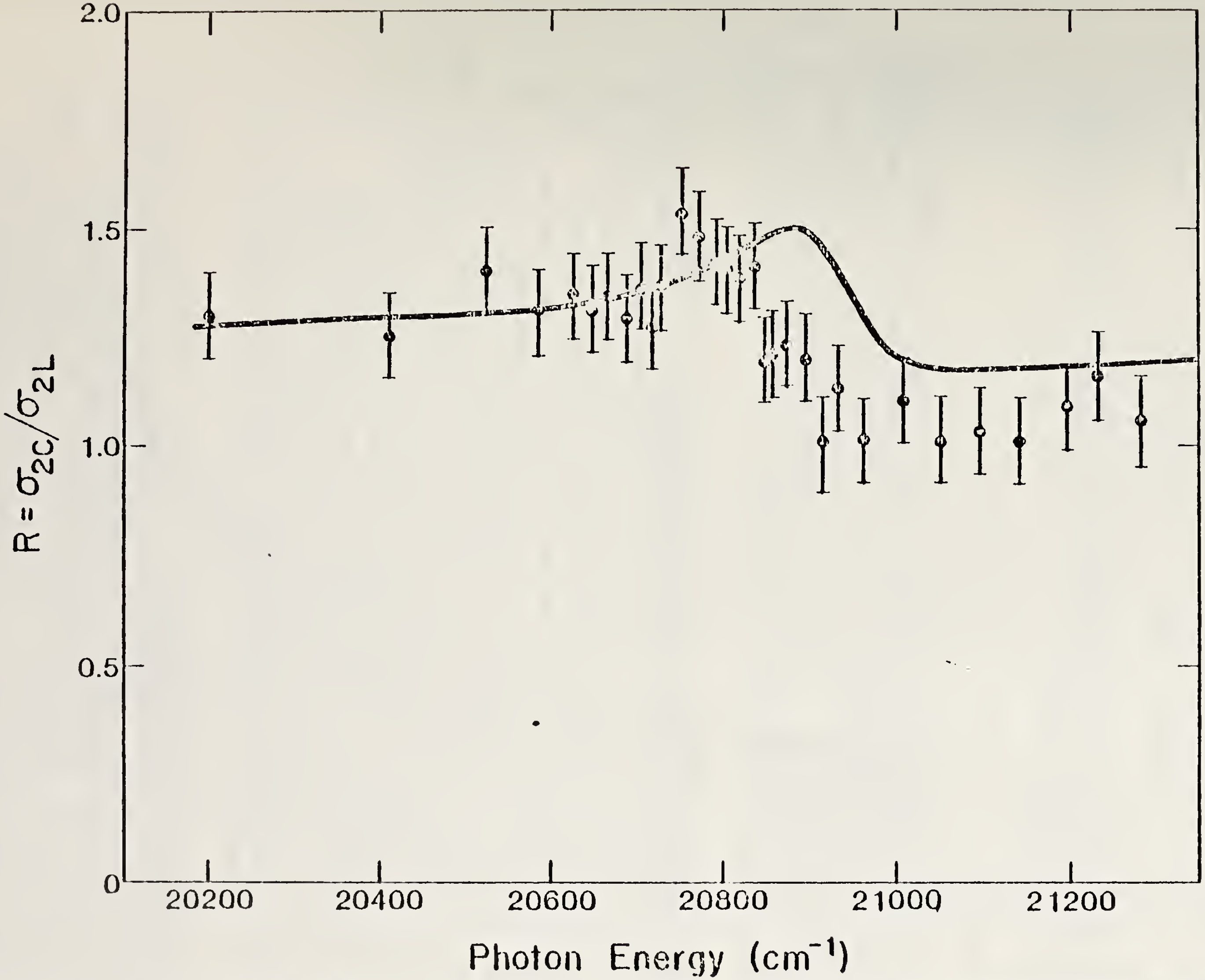



Fig. 27. Calculation of $R = \sigma_{2C}/\sigma_{2L}$ for Cs in the vicinity of the interference minimum (solid line). The points are the measurements of Normand and Morellec.

laser intensity. However, the observed strong asymmetry of the line does not come out of the lowest order perturbation treatment. A very approximate higher order perturbation calculation did exhibit asymmetries in qualitative agreement with the experiment. This problem will be studied from a quasimolecular point of view to see if the observed line asymmetry can be understood in a simpler way. Also being studied, in collaboration with a Saclay program on laser-induced ionization in Na vapor, is the effect of a laser field on the rate of associative ionization

$$Na(3p) + Na(3p) \rightarrow Na_2^+ + e \quad .$$

This process goes via a curve-crossing and photons are not needed for energy conservation, but their presence may enhance the effective rate by providing alternate channels.

## Chemical Physics

Much of the work in this category could probably be included in the category "Atomic and Molecular Physics and Interactions," or conversely, some of the work in that category could be included here. However, it is important to emphasize that JILA has a very strong chemical physics program with three Fellows rostered in the Department of Chemistry (Lineberger [CU], Reinhardt [CU], and Leone [NBS]). It is Leone's work listed here as part of the QPD program.

Translation-to-Vibration Excitation Transfer. F. Magnotta (NRC Postdoc), D. Nesbitt, and S. Leone have developed a new method to study translation-to-vibration (T-V) excitation transfer. T-V processes are important in plasmas and shock-heated gases, and can be related to emissions observed from the upper atmosphere and interstellar media. The new technique utilizes a short wavelength (193 nm) pulsed excimer laser to produce translationally "hot" D and H-atoms by photodissociation of $HC\ell$, HBr, or $H_2S$. The atoms have energies between 2 and 3 eV. Upon collision of these atoms with other molecules, emission is observed from vibrational states excited by T-V transfer. For example, collision of a fast H with $HC\ell$ results in vibrational excitation in the $HC\ell$ as high as v=5. Precision measurements have been made on the translational slowing, or moderator efficiency, of the H-atoms by rare gases (Fig. 28). The distribution of vibrationally excited states and atom exchange cross sections have been obtained for collisions of $H + HC\ell$, $H + DC\ell$, $D + HC\ell$, and $D + DC\ell$. The results show that both inelastic and reactive collisions are responsible for the excitation.

Ion-Molecule Reaction Dynamics. T. Zwier, J. Weisshaar, and S. Leone are studying ion-molecule reaction dynamics via infrared chemiluminescence in a flowing afterglow. Complete vibrational state distributions have been obtained for the products of the reactions: $F^- + HX \rightarrow HF(v) + X^-$ ($X = C\ell$, Br and I) and $F^- + H \rightarrow HF(v) + e^-$. The results show that a substantial fraction of the reaction energy is deposited into product vibration. The populations observed in the $H + F^-$ associative detachment reaction are in good agreement with

Table 1.

T-V Moderator Efficiency

| Moderator M | Calculated $\sigma_{T-T'}$ ($A^2$) | Calculated ratio (relative to He) | Measured ratio (relative to He) HCℓ | HBr |
|---|---|---|---|---|
| He | 3.3 | 1.0 | 1.0 | 1.0 |
| Ar | 0.75 | 0.23 | 0.28 | 0.23 |
| Kr | 0.40 | 0.12 | -NM- | 0.13 |
| Xe | 0.31 | 0.095 | 0.11 | 0.093 |

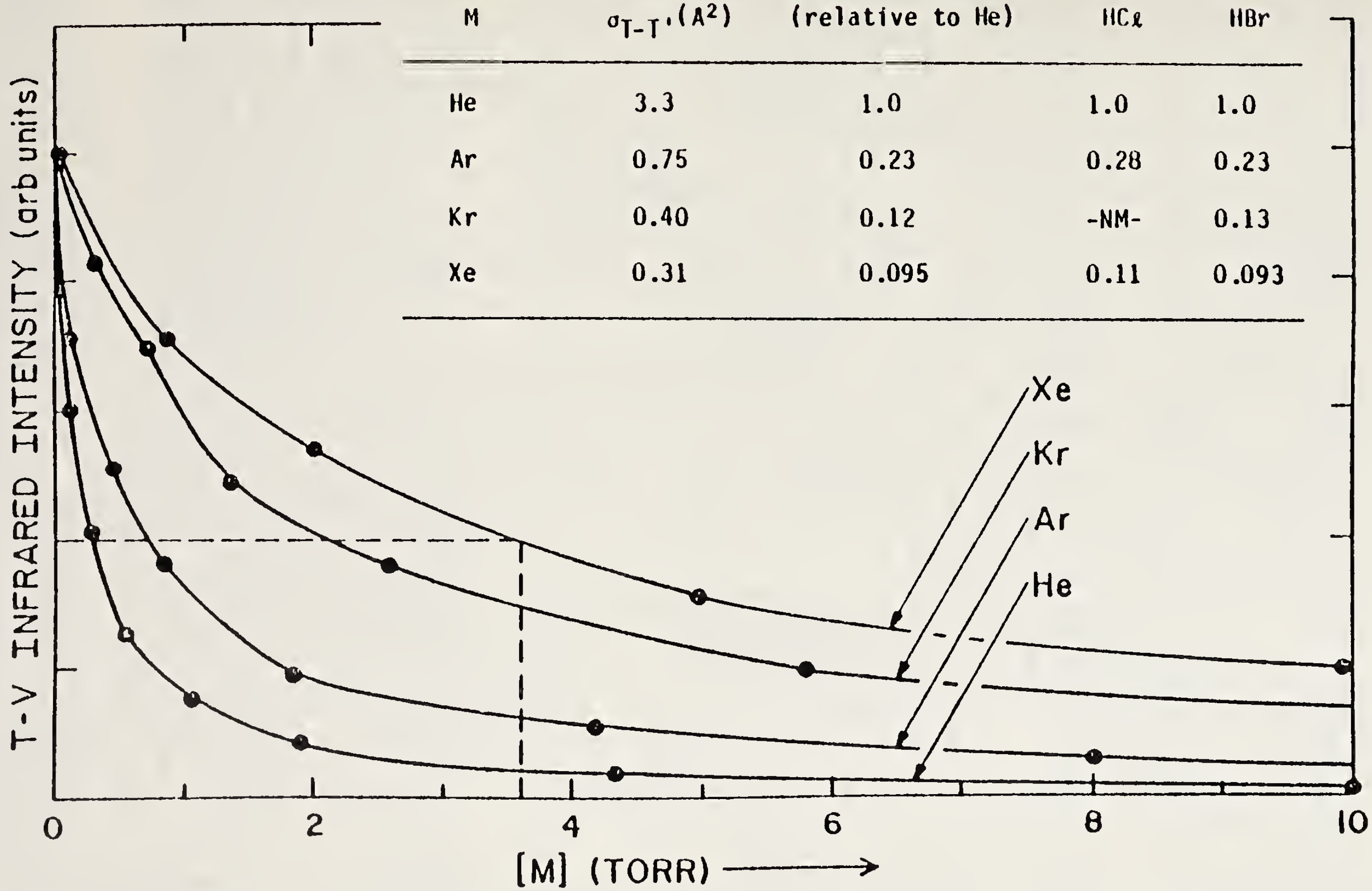



Fig. 28. Experimentally observed T-V excited HBr(v) signal intensity as a function of moderator buffer gas pressure. The ratio of pressures required to reduce the peak signal intensity to a fixed level (0.4 is shown by the horizontal dotted line) is the inverse of the inert gas moderating efficiencies (see table inset).

recent calculations in the literature which use virtual state models and consider dynamical transitions induced by the nuclear motion. These methods are presently being extended by M. Smith, V. Bierbaum, and S. Leone to study the associative ionization processes $Ar^*$, $Ne^* + H \rightarrow ArH^+(v)$, $NeH^+(v) + e^-$.

Recently, two major new developments have been introduced to the study of ion-molecule reaction dynamics. Laser-induced fluorescence has been used by T. Zwier, J. Weisshaar, and S. Leone to probe the $CO^+(v)$ product states in the thermal energy charge transfer reaction: $N^+ + CO \rightarrow N + CO^+(v=0,1,2)$. The results are similar to, but quantitatively different from predictions based on simple Franck-Condon models of the charge transfer. The laser probe method allows some of the first measurements on vibrational deactivation to be made. Preliminary estimates show that deactivation of $CO^+(v=1)$ by symmetric charge transfer with CO is ~0.5 Langevin. Near resonant vibration-to-vibration energy transfer of $CO^+(v=1)$ to $N_2$ is also extremely rapid, $\gtrsim 0.1$ Langevin. This work will be continued by C. Hamilton (NSF predoctoral fellow) and M. Duncan (NRC Postdoc). A second major development involves the completion and successful operation of a low pressure ion-reaction apparatus, in which both vibrational and rotational state distributions of ion-molecule reactions will be obtained. D. Guyer, L. Hüwel (Max-Planck fellowship), and S. Leone have obtained the first laser-induced fluorescence spectra of thermalized ions cooled in a mild supersonic jet. The jet of ions will be crossed with other reagents and the products of ion-molecule reactions interrogated. The first reactions to be studied will be charge transfer (e.g., $Ar^+ + N_2 \rightarrow Ar + N_2^+(v,J)$) and associative detachment (e.g., $O^- + H \rightarrow OH(v,J) + e^-$). Important information about the reactive dynamics will be obtained for the first time especially from the rotational state information in the products.

Laser-Initiated Chain Reactions. D. Nesbitt, D. Dolson (NRC Postdoc), and S. Leone are studying laser-initiated chain reactions. The development of these methods have taken on tremendous commercial importance with the discovery in Germany of a laser-initiated chain reaction synthesis of the industrially important vinyl chloride molecule. The work at JILA, which has pioneered this field, has progressed into the study of complex hydrocarbon chlorination chain reactions and the detection of extremely slow chain reactions that often go unnoticed. An offshoot of this work involves the recent development by L. Kovalenko and S. Leone of a method to make absolute reaction rate constant determinations for methyl radical reactions.

Photofragmentation Dynamics. Basic photofragmentation dynamics of $CH_3I$ has been studied by H. Hermann (DFG fellowship) and S. Leone to determine potential constants and vibrational state distribution for the $CH_3$ out-of-plane ("umbrella") vibration. Figure 29 shows the low resolution spectrum of $CH_3$ obtained in emission after the photolysis of $CH_3I$

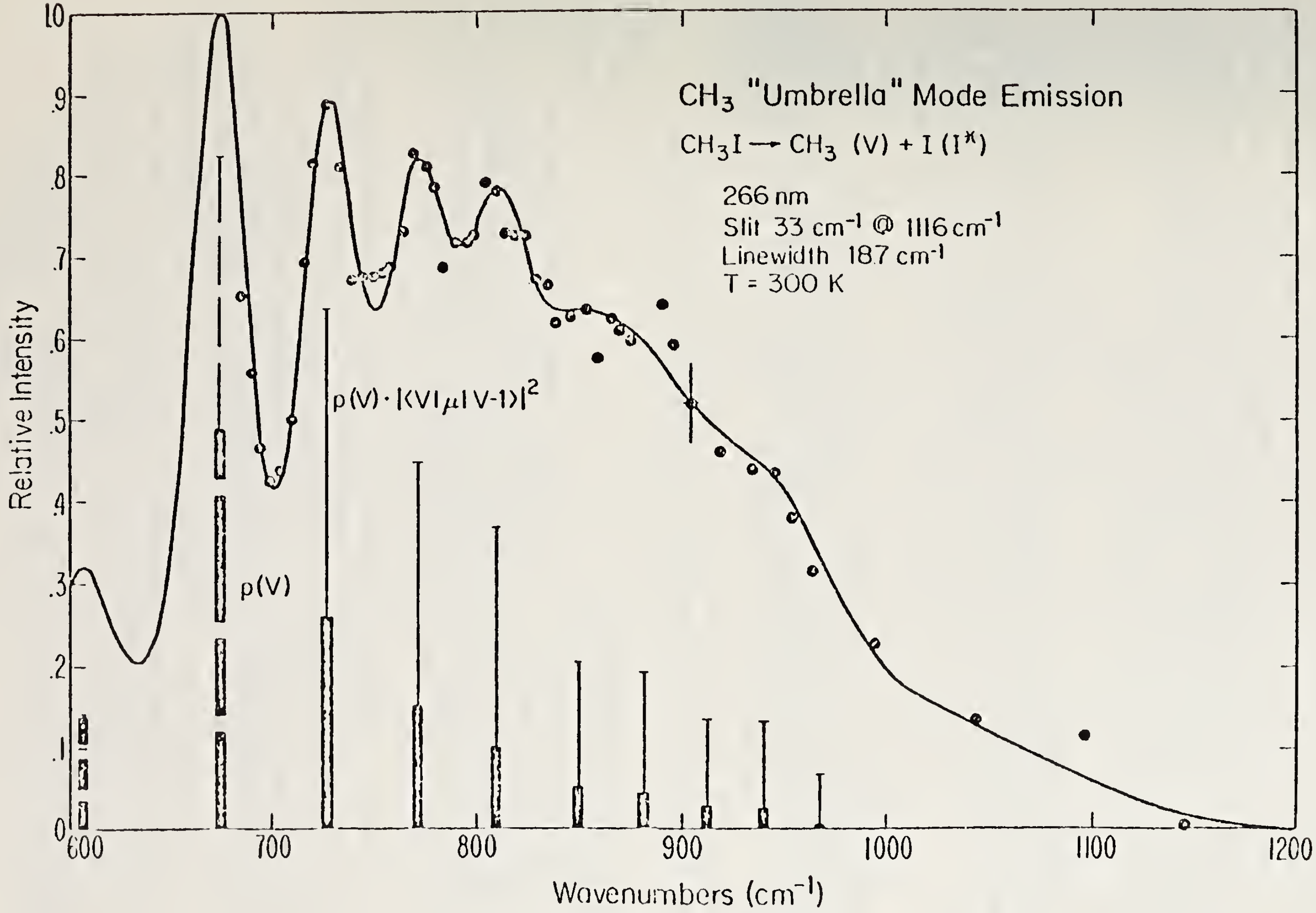



Fig. 29. Experimentally observed low resolution infrared emission spectrum of $CH_3(\nu_2)$ immediately after the photolysis pulse. The dots • are data points. The solid line is the best fit to the data, giving the nascent populations shown (solid bars).

at 266 nm. Each peak in the spectrum corresponds to a Q-branch feature of a vibrational band. The positions of three bands were obtained directly from the data: v = 3-2 (727 $cm^{-1}$), 4-3 (770 $cm^{-1}$), and 5-4 (810 $cm^{-1}$). From these frequencies and an earlier determination in the literature of the v = 1-0 position at ~605 $cm^{-1}$, the harmonic + quartic potential function for the umbrella mode was derived. From the amplitudes of the emission bands, the vibrational populations produced in the dissociation were obtained and have been compared to accurate theoretical calculations on the dissociation dynamics. The study of photofragmentation dynamics is being expanded with new work by J. Smedley and S. Leone to understand dissociation in molecules which yield excited state species suitable for direct solar pumping of lasers.

Spin Changing Collisions. Spin changing collisions in atomic calcium vapor are being studied by M. Hale and S. Leone using fully time-resolved kinetic methods. Thus far buffer gas induced transfer from the 4s5p $^1P_1 \rightarrow$ 4s5p $^3P_{2,1,0}$ levels has been measured. The cross sections for He, Ne, Ar, Kr, and Xe are ~34 Å$^2$, 6 Å$^2$, 4 Å$^2$, 17 Å$^2$ and 38 Å$^2$ respectively. The results do not follow the expected trend, with helium being anomalously high. One explanation involves the possibility that helium can penetrate the 5p orbital to interact with the $Ca^+$ ionic core. The perturbation of the charge symmetry could then induce the spin change more efficiently. The mechanism of these spin changing collisions will be investigated by further examination of the spherically symmetric 4s6s $^1S_0$ orbital which is near resonant with the 4s6s $^3S_1$ level.

## JILA Atomic Collisions Data Center

The year 1981 has been one of very great change in the Center -- changes which are continuing and will be in progress for sometime. Prominent in the changes is the departure of Dr. Earl Beaty, Director of the Center, who as a result of the large (10%) reduction in force at NBS is now on duty in the Time and Frequency Division of NBS.

In January 1981, a change of philosophy and direction was determined for the Center. The advisory committee of JILA staff scientists formed in 1980 became very active in the Center and its expertise utilized in the choice and planning of projects. Evaluated compilations and reviews will be emphasized, while published bibliographies will be deemphasized. Projects of well-defined scope will be planned, so that the amount of data concerned is manageable by the available facilities and projects can be started and completed in intervals of a few months. Appropriate scientists from outside JILA will be invited to work at the Data Center on the evaluation and review of data, and the JILA scientific staff, both permanent and visiting, will be urged to participate in these activities.

With this policy in mind, several compilation-review type projects have been started. In collaboration with J. Dutton (University of Swansea, Wales), work was started in August 1980, on a review of swarm data in electronegative gases, and this project is nearing completion. J. Alan Rees (University of Liverpool, United Kingdom) spent the interval of October 1980 to April 1981 at the Data Center working on a review of differential elastic scattering cross sections for atoms. Y.-K. Kim (Argonne National Laboratory) is spending July and August 1981 on review and analysis of data on secondary electron spectra of atoms and molecules. Steve Leone (JILA) embarked on a compilation of vibrational energy transfer rates of hydrogen halides in June 1981. W. Carl Lineberger (JILA) began work in July 1981 on an update to his review of electron affinities in atoms. All of these projects have involved the Information Center Staff in bibliographic search, collection of related publications, and compilation of numerical data. In early 1980 Ara Chutjian expressed interest in reviewing data on vibrational excitation of molecules by electron impact. Publications and data for this project were collected and sent to Dr. Chutjian, who is considering spending a month (November 1981) at JILA to complete the manuscript for his review. All of these projects are scheduled for completion in FY 1982.

In the spirit of change in direction of the Information Center efforts, arrangements were made in June 1981 to do computer searches of bibliographic data bases using the Lockheed Dialog System. We are now on-line to this system and expect to employ it for all compilation projects.

In the area of modernizing operating procedures, the bibliographic data base was moved from the now-defunct XDS 940 computer (NOAA) to indexed sequential files on the CDC 750. Programs were completed for dependable read/write of ASCII tapes on the CDC 750. Programs were completed to make camera-ready tables and multi-curve graphs using our in-house microcomputer system. Work is in progress on interrogation of our bibliographic data base on various descripters and comprehensive handling of numerical data using the CDC 750. The latter item would include data manipulation and preparation of camera-ready figures and tables. Exploration has begun on the feasibility of use of the CDC 750 Data Base Management System, initially for loading numerical data into a data base.

A search for a manager-director of the Information Center to fill the gap left by the departure of Dr. Beaty was begun in June 1981. The advisory committee, with a few additions, is forming the Search Committee.

Various publications have been completed in FY 1981. They include:

1. "Data Index for Energy Transfer Collisions of Atoms and Molecules, 1970-1979," NBS Special Publication 593, J. W. Gallagher, Janet Van Blerkom, E. C. Beaty, and J. R. Rumble, Jr. (April 1981).

2. "Bibliography of Low Energy Electron and Photon Cross Section Data (1979)," Jean W. Gallagher and Earl C. Beaty, JILA Information Center Report No. 21 (January 1981).

3. "Multiphoton Bibliography 1979," NBS Publication LP-92, Suppl. 2, 51 pages, J. H. Eberly, J. W. Gallagher, and E. C. Beaty (October 1980).

FY 1982 Plans. Plans for FY 1982 are in keeping with the newly-established direction of producing more evaluated compilations and reviews. The projects mentioned above, all scheduled for completion in FY 1982, are itemized under Milestones below. Plans are, of course, subject to revision -- particularly if the new Director of the Center sees better directions to take.

Additional similar projects are planned. Mike Shull (JILA) will continue his work in compiling collision strengths for electron-impact excitation of ions in high-temperature plasmas and, with the help of the Information Center staff, will compile tables by isoelectronic sequence and describe temperature dependences of the collision strengths.

Work has been ongoing at the Data Center to compile elastic, momentum transfer, and electronic excitation cross sections for electron collisions with atoms. J. Gallagher and J. R. Rumble will produce a series of compilations of these data, divided by atomic species. This series will be started in early 1982.

A. V. Phelps (JILA) will evaluate and compile a recommended set of electron collision cross sections for $N_2$ beginning in the summer of 1982.

Some projects are tentative, depending on uncertain schedules and commitments of scientists outside of JILA. These include a compilation and review by Robert Bernheim of the Pennsylvania State University of the molecular structure and spectral data for the ground and excited electronic states of the alkali metal diatomic molecules and a compilation and review by Jeffrey I. Steinfeld of MIT of state-specific collisional energy transfer rates in the diatomic halogens. Presumably Bernheim's work might be done between September 1981 and June 1982 and Steinfeld's during the summer of 1982. Both of these projects would deal with timely topics and be conducted by well-recognized experts. Both would place heavy demands on Information Center staff, but are predicted to produce very worthwhile results. An alternate project, should either of these scientists be unavailable, would be a compilation of data on photoabsorption and photoionization in the vacuum ultraviolet with minimal advisory participation by Anthony F. Starace and J. A. R. Samson of the University of Nebraska.

In the area of operating procedures, plans are to continue the work in progress on computer programs for handling numerical data, possible implementation of the CDC Data Base Management System, to interface the Lockheed output with the local machine-readable medium, to provide program support for editing the Lockheed output, and to establish working procedures for information exchange with other data centers.

There are topics adjacent to the areas historically covered by the Center in which research activity is currently high and which are not now within the established subject area of existing data centers. Though there are currently no plans to specifically expand into these areas, for the purpose of planning a timely evolution of the JILA Information Center, the possibility of extending our activities into one or more of these will be reviewed with the advisory committee, staff scientists and outside experts. These topics include: (1) astrophysics; i.e., processes involving highly ionized species and interstellar molecules; (2) chemical physics; e.g., electronic potential surfaces in excimers, population distributions in chemical reactions, and radiationless processes represented by lifetime tables; (3) laser related physics; e.g., absorption coefficients, lifetimes and $\phi_f$'s of laser dyes, nonlinear optical coefficients, data describing laser-induced collision phenomena, and multiphoton absorption, ionization and dissociation; (4) applied physics; e.g., parameters describing supersonic jet technology.

<u>Milestones FY 1982</u>

1. "A Survey of Electron Swarm Data in Electronegative Gases," Beaty, Dutton, Gallagher and Pitchford, to be submitted to JCPRD, 10/81.
2. "A Review of Differential Elastic Scattering Cross Sections," J. A. Rees and E. C. Beaty, to be submitted to JCPRD, 11/81.
3. "An Update to the Review of Atomic Electron Affinities," W. C. Lineberger, to be submitted to JCPRD, 12/81.
4. "A Compilation of Vibration Relaxation Rates in Hydrogen Halides," S. Leone, to be submitted to Atomic and Nuclear Data Tables or JCPRD, 12/81.
5. "Recommended Electron Scattering Cross Sections for Vibrational Excitation of Diatomic and Polyatomic Molecules," A. Chutjian, to be submitted to JCPRD, 2/82.
6. "A Review of Secondary Photoelectron Spectra: I. He, $N_2$," Y.-K. Kim, JILA Information Center Report, 3/82. To be submitted with subsequent sections, but without extensive tables, to JPCRD or Reviews of Modern Physics.
7. "A Review of Secondary Photoelectron Spectra: I. $O_2$, $H_2$," Y.-K. Kim, JILA Information Center Report, 10/82. (See Milestone 6).
8. "Collision Strengths for the He Isoelectronic Sequence," M. Shull.
9. "A Compilation of Elastic, Momentum Transfer, and Electronic Excitation Cross Sections for the Rare Gases," J. Gallagher and J. R. Rumble, to be submitted to JCPRD, 7/82.
10. Computer programs described above to be completed, 6/82.

## III. PUBLICATIONS AND INTERACTIONS

Included in the following pages of this section are tables of

- JILA Visiting Fellows for 1980-81 and 1981-82.
- Publications during the past year of NBS Fellows and Visiting Fellows.
- Invited papers (talks) of NBS personnel of QPD.
- Technical and professional committee participation and leadership of QPD personnel.
- Consulting by QPD personnel.
- Trips of QPD personnel sponsored by others.
- Conferences sponsored.
- Seminars and colloquia.
- Other items of interest to the Panel.

## III. PUBLICATIONS AND INTERACTIONS

### VISITING FELLOWS

### Quantum Physics Division (525)

| VISITING FELLOWS - FY 1981 | HOME INSTITUTION | AREA OF WORK |
|---|---|---|
| Bruno Bertotti | Istituto di Fisica Teorica<br>Universita di Pavia<br>Pavia, Italy | Test of gravitational theory, studies of gravity experiments in space. |
| G. Leuchs | Sektion Physik<br>University of Munchen<br>8046 Garching<br>Am Coulombwall 1<br>West Germany | Investigation of Rydberg-atoms. |
| H. Warren Moos | Department of Physics<br>The Johns Hopkins University<br>34th & Charles Streets<br>Baltimore, MD 21218 | Ultraviolet observations of planetary atmospheres from sounding rockets, satellites, and planetary spacecraft. |
| Francis M. Pipkin | Lyman Laboratory of Physics<br>Harvard University<br>Cambridge, MA 02138 | Experimental atomic physics and elementary particle physics. |
| Saul A. Rappaport | Massachusetts Institute of Technology<br>Center for Space Research<br>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. |

## VISITING FELLOWS

### Quantum Physics Division (525)

| VISITING FELLOWS - FY 1981 | HOME INSTITUTION | AREA OF WORK |
|---|---|---|
| Edward L. Robinson | Department of Astronomy<br>University of Texas at Austin<br>Austin, TX 78712 | Observational astronomy; oscillation of white dwarfs and cataclysmic variables. |
| Hugh G. Robinson | Department of Physics<br>Duke University<br>Durham, NC 27706 | Precision measurements with optical pumping. |
| David Spence | Argonne National Laboratory<br>9700 S. Cass Avenue<br>Argonne, IL 60439 | Electron collisions with atoms and molecules using trapped-electron techniques. |

## VISITING FELLOWS

### Quantum Physics Division (525)

| VISITING FELLOWS - FY 1982 | HOME INSTITUTION | AREA OF WORK |
|---|---|---|
| Girish S. Agarwal | School of Physics<br>University of Hyderabad<br>Hyderabad - 500 001<br>India | Light scattering and quantum optics. |
| Allen Joel Anderson | Institute of Geophysics<br>Hällby<br>S-755 90 Uppsala<br>Sweden | Solid earth geophysics; gravitational field of the earth. |
| Robert A. Bernheim | Department of Chemistry<br>The Pennsylvania State University<br>152 Davey Laboratory<br>University Park, PA 16802 | Energy transfer and reaction dynamics. |
| Brian H. Bransden | Department of Physics<br>University of Durham<br>South Road<br>Durham, England DH1 3LE | Theory of atomic collisions. |
| Lawrence W. Davis | Physics Department<br>University of Idaho<br>Moscow, ID 84843 | Optically pumped cw lasers |
| Teije de Jong | Astronomical Institute<br>University of Amsterdam<br>Roetersstraat 15<br>1018 WB Amsterdam<br>The Netherlands | Interstellar medium and late-type giant stars. |

VISITING FELLOWS

Quantum Physics Division (525)

| VISITING FELLOWS - FY 1982 | HOME INSTITUTION | AREA OF WORK |
|---|---|---|
| Ratko K. Janev | Institute of Physics<br>Studentski trg 12/V<br>P. O. Box 57<br>11001 Belgrade<br>Yugoslavia | Collision processes of atoms and molecules with multiply charged ions. |
| C. Bradley Moore | Department of Chemistry<br>University of California<br>Berkeley, CA 94720 | Laser photochemistry. |
| Daniel R. Moore, II | Department of Mathematics<br>Imperial College<br>Huxley Building<br>Queen's Gate<br>London SW7 2BZ<br>Great Britain | Applied mathematics. |
| David T. Wilkinson | Department of Physics<br>Jadwin Hall<br>Princeton University<br>Princeton, NJ 08544 | Gravitation and cosmology. |

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E. C. Beaty, J. Dutton, and L. Pitchford, Electron Swarm Data Relevant to High-Voltage Insulation, in Gaseous Dielectronics II, Proceedings of the Second International Symposium on Gaseous Dielectronics, Knoxville, Tenn., March 9-13, 1980 (Pergamon, Oxford, 1980), pp. 25-31.

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P. L. Bender, Establishment of Terrestrial Reference Frames by New Observational Techniques, On Reference Coordinate Systems for Earth Dynamics, Vol. II (D. Reidel, Dordrecht, 1981), pp. 23-36.

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* (Y. Rabin, M. Berman), and A. Ben-Reuven, Theory of Double Resonance Raman Amplifier, J. Phys. B: Atom. Molec. Phys. 13, 2127-2136 (1980).

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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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* A. Ben-Reuven, Theory of Two-Atom Coherence in Gases. II. Continuous-Wave Spectra, Phys. Rev. A 22, 2585-2597 (1980).

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* A. Ben-Reuven, Resonance Absorption and Scattering of Strong Coherent Radiation in Thermally Relaxing Systems, in Lectures on Biological and Chemical Physics: A Symposium in Honour of Shneior Lifson on His 65th Birthday (in press).

* B. Bertotti, Statistics of Narrow Structures of the Gravity Field of the Earth. I. General Theory, J. Geophys. Res. (in press).

* G. Chanmugam, Cyclotron Absorption in Accreting Magnetic White Dwarfs, Astrophys. J. 241, 1122-1130 (1980).

* G. Chanmugam and (G. A. Dulk), Polarized Radiation from Hot Plasmas and Applications to AM Herculis Binaries, Astrophys. J. 244, 569-578 (1981).

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* G. Chanmugam, Cyclotron Emission From AM Herculis, in The Universe at Ultraviolet Wavelengths: The First Two Years of International Ultraviolet Explorer (NASA Conference Publication 2171, 1981), pp. 515-519.

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Quantum Physics Division (525)

* E. L. Robinson, (E. S. Barker, A. Cochran, W. D. Cochran, and R. E. Nather), MV Lyrae: Spectrophotometric Properties of Minimum Light or on MV Lyrae Off, Astrophys. J. (submitted).

* E. L. Robinson, (R. E. Nather, and S. O. Kepler), BT Monocerotis: A New and Unusual Eclipsing Nova, Astrophys. J. (submitted).

* E. L. Robinson, (S. O. Kepler, and R. E. Nather), Multicolor Variations of the ZZ Ceti Stars, Astrophys. J. (submitted).

* J. L. Hall, L. Hollberg, T. Baer, and H. G. Robinson, Optical Heterodyne Saturation Spectroscopy, Appl. Phys. Lett. (submitted).

* (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).

* (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. Spence, (W. A. Chupka, and C. M. Stevens), Search for Long-Lived Doubly Charged Atomic Negative Ions, Phys. Rev. A (submitted).

INVITED TALKS

Quantum Physics Division (525)

G. H. Dunn, "Experimental Results for Electron Impact Excitation and Ionization of Ions," Conference on Atomic Processes in High Temperature Plasmas, topical conference of the American Physical Society by the Division of Electron and Atomic Physics, Louisiana State University, Baton Rouge, Louisiana, February 27, 1981.

A. C. Gallagher, "Molecular Continuum Radiation as a Reaction Diagnostic," University of Toronto, Physics and Chemistry Colloquium, April 20, 1981.

A. C. Gallagher, "The Absorption and Emission of Radiation by the Collision Complex," XII ICPEAC, July 16, 1981.

S. Geltman, "Separated-Atom Theory of Laser Induced Collisional Excitation Transfer and Ionization," (two talks), Conference on Photon-Assisted Collisions, June 22-24, 1981, Instituto di Chimica Quantistica, Pisa, Italy.

S. R. Leone, "Nascent Product Vibrational State Distributions of Simple Ion-Molecule Reactions," Dept. of Chemistry, Colorado State Univ., Fort Collins, Colorado, October 1980.

S. R. Leone, "Simple A+BC Reaction Dynamics with a Negative Ion Twist," Department of Chemistry, University of Denver, Denver, Colorado, November 1980.

S. R. Leone, "Vibrational Product State Distributions of Ion-Molecule Reactions, Symposium on "Chemistry and Dynamics of Ions and Molecules in the Gas Phase," 16th Midwest Regional American Chemical Society Meeting, Lincoln, Nebraska, November 1980.

S. R. Leone, "Ion Molecule Reaction Dynamics in the Gas Phase," The James Franck Institute, University of Chicago, February 1981.

S. R. Leone, "Dynamics of Negative Ion Reactions," Department of Chemistry, Illinois Institute of Technology, February 1981.

S. R. Leone, "Infrared Emission Studies of Laser-Produced Free Radicals and Chain Reactions," General Motors Research Laboratory, Warren, Michigan, February 1981.

S. R. Leone, "Photofragmentation Infrared Emission Spectroscopy," Workshop on Far UV Spectroscopy and Photochemistry, Mülheim, West Germany, March 1981.

S. R. Leone, "Dynamics of Gaseous Ion-Molecule Reactions," Max-Planck-Institut für Strömungsforschung, Gottingen, West Germany, March 1981.

## INVITED TALKS

### Quantum Physics Division (525)

S. R. Leone, "Properties of Laser Radiation," "Detection of Radiation," "V-V, V-RT Small Molecules," and "Laser-Induced Chain Reactions," Lectures for Lasers in Chemistry Workshop, University of Utah, held at Snowbird, Utah, September 1981.

J. L. Linsky, "Stellar Chromospheres, Coronae, and Winds," Invited review paper presented at the Meeting on Solar Instrumentation, Sacramento Peak National Observatory, Sunspot, New Mexico, October 16, 1980.

J. L. Linsky, "The Solar Physics of Nearby Stars," Invited colloquium presented at an Astro-Geophysics Departmental Meeting, University of Colorado, Boulder, Colorado, October 27, 1980.

J. L. Linsky, "Chromospheres and Coronae of Stars," Invited colloquiums:

Physics Department, Gettysburg College, Gettysburg, Pennsylvania, October 29, 1980.

NASA Goddard Space Flight Center, Greenbelt, Maryland, October 31, 1980.

J. L. Linsky, "Stellar Chromospheres and Coronae: Recent Results from Einstein and IUE," Invited colloquiums:

NASA Ames Research Center, Moffett Field, California, February 17, 1981.

Astronomy Department, Penn State University, University Park, Pennsylvania, February 23, 1981.

Astronomy Department, University of Toronto, West Hill, Ontario, Canada, March 4, 1981.

High Altitude Observatory, National Center for Atmospheric Research, Boulder, Colorado, April 9, 1981.

J. L. Linsky, "Stellar Chromospheres and Coronae: Recent Results from the Einstein X-ray Observatory and the International Ultraviolet Explorer Satellites," Invited colloquium presented at the NOAA Space Environment Lab, Boulder, Colorado, March 31, 1981.

D. W. Norcross, "The Theory of Inelastic Electron-Atomic Collisions," Invited review paper to be presented at the 14th National Atomic and Molecular Physics Conference, Newcastle upon Tyne, England, March 30, 1982.

D. W. Norcross, "The Theory of Electron Collisions with Polar Molecules," Invited paper to be presented at the Electron Collisions Workshop, Newcastle upon Tyne, England, April 2, 1982.

## TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

### Quantum Physics Division (525)

P. L. Bender, Member, Ad Hoc Committee on Gravitational Physics of the Space Science Board, 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, Member, Laser Geodynamics Satellite (LAGEOS) Working Group, NASA.

P. L. Bender, Member, Physics Department Advisory Council, Princeton University.

P. L. Bender, Internal University of Colorado Review Panel for the Astro-Geophysics Department.

G. H. Dunn, Chairman, Organizing Committee, Conference on Atomic Processes in High Temperature Plasmas. Held in Baton Rouge, Louisiana, February 1981. A Topical Conference of the American Physical Society.

G. H. Dunn, Member, Committee for Davisson-Germer Prize.

J. E. Faller, Member, Special Study Group 3.37 "Special Techniques of Gravity Measurements," of the International Gravity Commission.

J. E. Faller, Member, Plans Committee of the Geodesy Section of the AGU.

J. E. Faller, Member, Fellows Committee of the AGU, Chairman for External Awards.

A. C. Gallagher, Member, ICPEAC Organizing Committee.

K. B. Gebbie, Vice Chairman, Colorado Passenger Tramway Safety Board.

K. B. Gebbie, Member, Electorate Nominating Committee, Section D, American Association for the Advancement of Science.

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.

## TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

### Quantum Physics Division (525)

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, Editorial Board, Computer Physics Communications.

S. R. Leone, Organizer of Symposium on New Techniques in Chemical Kinetics, American Chemical Society Meeting, New York City, August 1981.

S. R. Leone, Co-Chairman, Gordon Conference on Molecular Energy Transfer for 1985.

S. R. Leone, Associate Editor, Optics Letters.

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.

J. L. Linsky, Member, NSF Astronomy Research Section Oversight Committee, National Science Foundation.

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, Panel on Ultraviolet, Optical, and Infrared Astronomy of the Astronomy Survey Committee, National Academy of Sciences and National Research Council.

D. W. Norcross, Chairman, Local Committee for Annual Meeting of Division of Electron and Atomic Physics, Boulder, Colorado, 1983.

D. W. Norcross, Member, Program Committee, Division of Electron and Atomic Physics of the American Physical Society, 1981.

A. V. Phelps, DARPA Committee on Beam-Generated Air Chemistry.

A. V. Phelps, Steering Committee for Workshop on Glow Discharge Opening Switches, January 1982.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Quantum Physics Division (525)

A. V. Phelps, Advisory Committee, NATO Advanced Study Institute on Electrical Breakdown and Discharges in Gases.

S. J. Smith, Member, Committee on Atomic and Molecular Sciences, National Academy of Sciences.

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, Member, Local Committee for Annual Meeting of Division of Electron and Atomic Physics, Boulder, Colorado, 1982.

S. J. Smith, Co-Chairman, JILA Workshop on Photoionization from Excited States of Atoms and Molecules, Boulder, Colorado, March 1981.

## CONSULTING

### Quantum Physics Division (525)

A. Gallagher

Dr. Gallagher is consulting with a group studying the production of hydrogenated amorphous silicon films at the Solar Energy Research Institute in Golden, Colorado.

S. Geltman

Dr. Geltman does consulting and advising with the Service de Physique Atomique, CEN de Saclay, France, on problems related to laser ionization of gases.

J. L. Hall

Dr. Hall is consulting with the Theoretical Astrophysics Group at Cal Tech in the area of laser techniques for gravity wave detection.

D. G. Hummer

Dr. Hummer consults for the X-ray laser project at Livermore Labs, and is one of three foreign consultants for the UK Collaborative Computational Project on Stellar Atmospheres, sponsored by the U.S. Science Research Council.

S. R. Leone

Dr. Leone does informal consulting with Texaco and Martin Marietta on laser chemistry and collaborates with General Motors Research Laboratories.

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)

| | |
|---|---|
| P. L. Bender | January 14-15, 1981 - Washington, D.C. Attended the meeting of ad hoc Gravity Gradiometer Review Panel at NASA Headquarters. Sponsor: Science Applications, Inc. |
| | January 20-22, 1981 - Clear Lake, Texas. Attended the meeting of the Committee on Earth Sciences of the Space Science Board, National Academy of Sciences. Sponsor: National Research Council. |
| | March 3-5, 1981 - 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. |
| | April 9-11, 1981 - Washington, D.C. Attended meeting of the Committee on Earth Sciences of the Space Science Board, National Academy of Sciences. Sponsor: National Research Council. |
| | June 1-4, 1981 - Greenbelt, Maryland. Participated in NASA Panel to review Crustal Dynamics projects proposals. Sponsor: NASA |
| | July 7-8, 1981 - Boston, Massachusetts. Assisted in editing of the report of the Panel on Crustal Movement Measurements of the Committee on Geodesy, National Academy of Sciences. Sponsor: National Research Council. |
| A. C. Gallagher | April 20-21, 1981 - Toronto, Ontario, Canada. Presented a seminar on molecular continuum radiation as a diagnostic of chemical reactions and visited labs at the University of Toronto. Sponsor: University of Toronto. |
| K. B. Gebbie | November 23-26, 1981 - Greenbelt, Maryland. Worked at NASA Goddard Space Flight Center as a Guest Investigator on the SMM/UVSP Experiment. Sponsor: NASA. |

## TRIPS SPONSORED BY OTHERS

### Quantum Physics Division (525)

K. B. Gebbie

January 6-10, 1981 - Taos, New Mexico.
Attended 1981 annual meeting of the Solar Physics Division of the American Astronomical Society and presented a contributed paper entitled, "Steady Flows in the Solar Transition Region Observed with UVSP Experiment on SMM."
Sponsor: NASA.

January 30 - February 5, 1981 - Greenbelt, Maryland.
At NASA/Goddard Space Flight Center analyzed data obtained with Solar Maximum Mission Satellite.
Sponsor: NASA.

D. G. Hummer

January 21 - February 1, 1981 - Cambridge, Massachusetts.
Collaborated with Dr. G. B. Rybicki on calculation of hydrogen line profile in accretion disks.
Sponsor: Smithsonian Institute.

April 19-22, 1981 - Livermore, California.
Participated in workshop on calculational methods in dynamic line transport held at Livermore and discussed with Livermore personnel the possibility of a contract for research in radiation transport in moving media.
Sponsor: Lawrence Livermore Laboratory.

July 9-19, 1981 - London, England and Gregynog, Wales.
Attended a four-day planning meeting of the UK Collaborative Computational Project on Stellar Atmospheres, a nation-wide collaborative project supported by the UK Science Research Council in Gregynog, Wales.
Worked with Dr. Peter Storey at University College on the discrepancies between results of recombination programs recently transferred from University College to JILA.
Sponsor: UK Collaborative Computational Project on Stellar Atmospheres.

S. R. Leone

November 5-6, 1980 - Lincoln, Nebraska.
Attended the 16th Midwest Regional American Chemical Society Meeting and gave a talk entitled, "Vibrational Product State Distributions of Ion-Molecule Reactions," at invited symposium on Chemistry and Dynamics of Ions and Molecules in the Gas Phase.
Sponsor: 16th Midwest Regional ACS Meeting.

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

S. R. Leone

February 3, 1981 - Chicago, Illinois.
Visited the James Franck Institute at the University of Chicago and gave a colloquium on "Ion Molecule Reaction Dynamics in the Gas Phase."
Sponsor: The University of Chicago

February 4, 1981 - Chicago, Illinois.
Visited the Illinois Institute of Technology and gave a colloquium on "Dynamics of Negative Ion Reactions."
Sponsor: Illinois Institute of Technology.

February 5, 1981 - Detroit, Michigan.
Visited General Motors Research Lab and gave a colloquium on "Infrared Emission Studies of Laser-Produced Free Radicals and Chain Reactions."
Sponsor: General Motors Corporation.

February 20 - March 6, 1981 - West Germany.
Visited with Hubert Hoffman of Battelle Institute in Frankfurt, West Germany.
Attended workshop on "Far Ultraviolet Spectroscopy and Photochemistry," and gave an invited lecture on "Photofragmentation Infrared Emission Spectroscopy," in Mulheim, West Germany.
Visited labs in Kaiserslautern, West Germany.
Visited labs at Max Planck Institutes in Munich and Göttingen, West Germany.
Sponsors: National Science Foundation
Max-Planck-Institut für Stromungsforschung.

September 20-25, 1981 - Snowbird, Utah.
University of Utah, Workshop on "Lasers in Chemistry."
Sponsor: University of Utah.

J. L. Linsky

October 29, 1980 - Gettysburg, Pennsylvania.
Gave invited colloquium at the Department of Physics, Gettysburg College on the topic "Recent Work on the Study of Stellar Chromospheres and Coronae."
Sponsor: Gettysburg College.

October 30-31, 1980 - Greenbelt, Maryland.
Attended a meeting at Goddard Space Flight Center of the Space Telescope High Resolution Spectrograph Instrument Development Team, and

TRIPS SPONSORED BY OTHERS

Quantum Physics Division (525)

J. L. Linsky

October 31, 1980 - Greenbelt, Maryland.
Gave NASA Goddard Space Flight Center Scientific Colloquium on "Recent Work on the Study of Stellar Chromospheres & Coronae."
Sponsor: NASA.

February 17, 1981 - San Francisco, California.
Discussed with colleagues at Lockheed the x-ray spectroscopic observation of the sun and presented an invited colloquium at NASA, Ames Space Flight Center.
Sponsor: NASA.

February 18-20, 1981 - San Francisco, California.
Attended meeting of Committee on Space Astronomy & Astrophysics of National Academy of Science at Stanford University.
Sponsor: National Academy of Sciences.

February 23, 1981 - State College, Pennsylvania.
Consulted with members of the Astronomy Department at Penn State and gave a colloquium.
Sponsor: Pennsylvania State University.

February 24-26, 1981 - Washington, D. C.
Participated as a member of the Review Committee for Astronomy Research Section of National Science Foundation.
Sponsor: National Science Foundation.

April 24, 1981 - Washington, D. C.
Attended a meeting of the Committee on Space Astronomy and Astrophysics.
Sponsor: National Academy of Sciences.

May 14-15, 1981 - Greenbelt, Maryland.
Attended a meeting at Goddard Space Flight Center of the Space Telescope High Resolution Spectrograph Instrument Development Team.
Sponsor: NASA.

June 29 - July 2, 1981 - Calgary, Alberta, Canada.
Attended a meeting of the American Astronomical Society, and presented a paper.
Sponsor: NASA.

## TRIPS SPONSORED BY OTHERS

### Quantum Physics Division (525)

| | |
|---|---|
| D. W. Norcross | August 1980 - August 1981 - Cambridge, Massachusetts. Extended travel to Smithsonian Center for Astrophysics. Sponsor: Smithsonian Institute. |
| | December 4-5, 1980 - Los Alamos, New Mexico. Consulted at Los Alamos Scientific Laboratory on atomic collision problems. Sponsor: Los Alamos Scientific Laboratory. |
| A. V. Phelps | June 27 - July 11, 1981 - Les Arcs, France. Participated in the NATO Advanced Study Institute. Presented lectures and learned of the European work on gas discharges for use in JILA/NBS and contract research. Sponsor: NATO Advanced Study Institute. |
| S. J. Smith | May 27 - June 2, 1981 - Lenox, Massachusetts. Worked with group on writing report for the Committee on Atomic and Molecular Science, National Academy of Science. Sponsor: National Academy of Science. |

## SPONSORED CONFERENCES

### Quantum Physics Division (525)

North American Workshop on Symbiotic Stars, June 22-24, 1981, at JILA. J. L. Linsky and R. E. Stencel were co-organizers.

Fifth Workshop on the Vacuum Ultraviolet Radiometric Calibration of Space Experiments, March 22-23, 1981, at NCAR in Boulder.
J. L. Linsky was the organizer.

A JILA Workshop on photoionization of excited atomic and molecular states, including cross-sections, angular distributions, spin polarization and wavelength dependence was held in March 1981.
S. J. Smith and G. Leuchs (Visiting Fellow) were co-organizers.

SEMINARS AND COLLOQUIA

Quantum Physics Division (525)

Informal Seminars

Name/Affiliation/Title/Date

R. Stencel (Research Associate) and G. Shaviv (JILA Visiting Fellow) - A Short Period Binary Model for HM Sge, November 7, 1980.

L. A. Willson (Univ. of Iowa) and G. Wallerstein (JILA Visitor) - A Long Period Binary Model for Eruptive Symbiotics, November 7, 1980.

B. W. Bopp (JILA Visitor) - Recent IR Observations of Symbiotic and Related Stars, November 7, 1980.

L. A. Willson (Univ. of Iowa) - Miras, Modes, and Mass Loss and Simple Symbiotic Systems, November 17, 1980.

D. M. Gibson (New Mexico Tech.) - Radio Stars: Making the Solar Connection, November 26, 1980.

J. Christensen-Dalsgaard (Inst. Chemia, Sart-Tilman, Liège, Belgium) - Radiative Transfer in Linear Stellar Oscillations, December 10, 1980.

J. L. Beauchamp (Cal. Tech.) - Infrared Laser Photochemistry, December 12, 1980.

M. Rodonó, (Catania Univ. Observatory) - Observations of Close Binary Systems: Studies of RS CVn and BY Dra Systems Under Way at Catania Observatory , February 10, 1981.

R. Roy (Univ. of Rochester) - Spontaneous Switching and Quantum Fluctuations in Dye Lasers, February 18, 1981.

W. Raith (Yale Univ.) - e-Li Impact Ionization with Polarized Particles, June 17, 1981.

H. Taylor (Univ. of Southern California) - Special Experimental Effects in Electron Scattering on Atoms and Molecules in Strong Laser Fields, June 23, 1981.

B. L. Moiseiwitsch (The Queen's University of Belfast) - What is the Behaviour of Ionization and Electron Capture Cross Sections at Very High Impact Energies?, July 22, 1981.

J. Kimman (F.O.M. Institute for Atomic and Molecular Physics, Amsterdam, The Netherlands) - Absorption of Additional Photons in the Multiphoton Ionization Continuum of Xenon--Experimental Study, July 24, 1981.

## SEMINARS AND COLLOQUIA

### Quantum Physics Division (525)

### Informal Seminars on Atomic and Radiation Theory

Name/Affiliation/Title/Date

W. P. Allis (JILA Visitor) - Asymptotic Limits of the Boltzmann Equation for Electrons, October 14, 1980.

C. W. Gardiner (Univ. of Waikato) - New Treatment of Laser Phase and Amplitude Fluctuations in Atomic Fluorescence Experiments, October 21, 1980.

B. Christensen-Dalsgaard (JILA Visitor) - Application of the Finite-Element Method in Electron-Atom Scattering, October 28, 1980.

S. Haan (Research Assistant) - Time Evolution of Resonant Multiphoton Ionization of Sodium, November 4, 1980.

A. Tip (F.O.M. Inst., Amsterdam) - Hydrogen Atoms Interacting with a Quantized Radiation Mode, November 18, 1980.

L. Pitchford (LASL) - Comparison of Methods for Electron Swarm Analysis, November 25, 1980.

D. F. Walls (JILA Visiting Fellow) - Quantum Analysis of Fluctuations in Nonlinear Optics, December 9, 1980.

J. H. Eberly (Univ. of Rochester) - The Transition to Chaos in an Exactly Soluble Quantum Model, March 10, 1981.

B. Carré (Service de Physique Atomique, Saclay) - Laser-induced Ionization in Sodium Vapour, August 6, 1981.

## SEMINARS AND COLLOQUIA

### Quantum Physics Division (525)

### Chemical Physics Seminars

Name/Affiliation/Title/Date

J. Leventhal (Univ. of Missouri) - Energy Transfer in Collisions Involving Laser Excited Sodium Atoms, October 3, 1980.

D. A. Dixon (Univ. of Minnesota) - Applications of Molecular Orbital Theory--The Electronic States of Trimethylene-methane and Theoretical Determination of Proton Affinities, October 10,1980.

J. C. Weisshaar (JILA Postdoc) - Formaldehyde Photochemistry: The Decay Mechanism of Single Rotational Levels of $S_1$, October 17, 1980.

D. F. Walls (JILA Visiting Fellow) - Order and Chaos in Non-Equilibrium Systems, October 24, 1980.

S. Chapman (Columbia University) - Reaction Dynamics of $O_3+NO \rightarrow O_2+NO_2$, October 31, 1980.

J. R. Taylor (Univ. of Colorado, Physics) - Three-body Scattering Rates, November 7, 1980.

J. D. Harvey (Univ. of Auckland) - Recent Developments in Dynamic Light Scattering, November 14, 1980.

N. Clark (Univ. of Colorado, Physics) - Ferro-electric Liquids, November 21, 1980.

J. T. Hynes (Univ. of Colorado, Chemistry) - Along the Reaction Coordinate in Liquids, December 5, 1980.

G. B. Ellison (Univ. of Colorado, Chemistry) - Photo-electron Spectroscopy and Reaction Dynamics of Ions, December 12, 1980.

R. Mead (Graduate Student), P. Schulz, C. Feigerle (Research Associates), and K. Burnett (JILA Member) - Chemical Physics Christmas Special, December 19, 1980.

P. Schulz (Research Associate) - Photodetachment of $OH^-$, March 6, 1981.

E. W. Smith (NBS, Boulder) - Model Microfield Methods: An Introduction, March 20, 1981.

D. McMahon (JILA Visiting Scientist) - Dielectric Friction in Polar Liquids and Gases, April 3, 1981.

SEMINARS AND COLLOQUIA

Quantum Physics Division (525)

Chemical Physics Seminars (continued)

Name/Affiliation/Title/Date

D. Spence (JILA Visiting Fellow) - Elucidation of Molecular Dynamics from Electron Scattering Experiments, April 10, 1981.

P. L. Jones (Fachbereich Physik der Univ. Kaiserslautern) - Somewhere Over the Rainbow: Supernumerary Structure in $Na_2$-Ne Rotationally Inelastic Scattering Cross Sections, April 24, 1981.

S. V. ONeil (JILA) - Computation in Chemistry: A Pedagogical Potpourri, May 1, 1981.

K. Evenson (NBS, Boulder) - Laser Magnetic Resonance of Free Radicals Important in Radio Astronomy, May 8, 1981.

## SEMINARS AND COLLOQUIA

### Quantum Physics Division (525)

### JILA Colloquium Speakers

Name/Affiliation/Title/Date

G. Leuchs (Univ. of Munich) - Quantum Interference Effects in Time Resolved Spectroscopy, October 15, 1980.

B. Kayser (Stanford Linear Accelerator) - Particle Physics--What is the Excitement About?, October 22, 1980.

K. Thorne, (Cal. Tech.) - Quantum Non-demolition Measurements: Circumventing the Heisenberg Uncertainty Principle in the Search for Gravity Waves, November 19, 1980.

H. Robinson (JILA Visiting Fellow) - Experiments Yielding Precise Ratios of Electron Magnetic Moments in Simple Atoms, November 25, 1980.

R. P. Bauman (JILA Visiting Fellow) - Why Johnny Can't Do Physics--Underlying Causes of Student Difficulties in Reasoning, February 11, 1981.

D. Abbott (JILA) - The Consequences of Mass Loss from Early-Type Stars, February 17, 1981.

P. Drummond (Univ. of Rochester) - Transverse Effects in Laser Pulse Propagation, February 24, 1981.

J. A. Eddy (NCAR) - Is the Sun Shrinking?, March 3, 1981.

D. Levy (Univ. of Chicago) - The Spectroscopy of Weakly Bound Organic Dimers, March 10, 1981.

W. Fairbank (Stanford Univ.) - Experimental Gravitational Wave Astronomy at Stanford, March 17, 1981.

K. A. McAfee (Bell Labs) - Energy Transfer and Charge Exchange Oscillations During $Ar^+$ and $N^+$ Collisions with Various Molecules, March 31, 1981.

F. M. Pipkin (JILA Visiting Fellow) - Fast Beam Measurements of the Lamb Shift in Hydrogen, April 15, 1981.

C. Wheeler (Univ. of Texas) - Black Holes in Active Galactic Nuclei, April 21, 1981.

B. Woodgate (Goddard Space Flight Center) - SMM Flare Observations and Plasma Diagnostics, May 12, 1981.

Y. M. Chan (JILA) - Telephones, Terminals, RS232, Modems and All That Jazz: Data Communications for the Pedestrian, May 28, 1981.

## OTHER ITEMS OF INTEREST TO THE PANEL

### Quantum Physics Division (525)

| Name | University and Departmental Committees Served On |
|---|---|
| Bender, P. L. | Internal University of Colorado Review Panel for the Astro-Geophysics Department |
| Dunn, G. H. | Graduate Committee, Department of Physics, |
| | JILA Executive Committee |
| | JILA Shops Committee |
| | JILA Data Center Advisory Committee |
| | Member, several thesis and examinations committees |
| | NML EEO Coordinator |
| Faller, J. E. | Chairman, JILA Shops Committee |
| Gallagher, A. C. | JILA Space Committee |
| | Thesis Committee for H. Gunn (University of Otago, Dunedin, New Zealand) |
| | Thesis Committee for S. Buckman (Flinders University, Adelaide, Australia) |
| Gebbie, K. B. | Thesis Committee for Michael Francis (Department of Astro-Geophysics, University of Colorado) |
| | Examinations Committee, Department of Astro-Geophysics, University of Colorado |
| | The Billings Award Committee, Department of Astro-Geophysics, University of Colorado |
| Geltman, S. | Secretary for JILA Visiting Scientists Program |
| Leone, S. R. | Chemical Physics Committee, University of Colorado |
| | JILA Colloquium Committee |
| | JILA Safety Committee |
| | JILA Executive Committee |
| | JILA Data Center Committee |
| | NBS Research Advisory Committee |
| Linsky, J. L. | Thesis Committee, Mark Giampapa (Astronomy Department, University of Arizona) |

## OTHER ITEMS OF INTEREST TO THE PANEL

### Quantum Physics Division (525)

| Name | University and Departmental Committees Served On |
|---|---|
| Phelps, A. V. | Chairperson, JILA (to December 31, 1980) |
| | CU Institute Directors Committee |
| | JILA Data Center Advisory Committee |
| Smith, S. J. | Co-Chairman, JILA Colloquium Committee |
| | JILA Executive Committee |
| | JILA Shops Committee |

## OTHER ITEMS OF INTEREST TO THE PANEL

### Quantum Physics Division (525)

| Name | Graduate Students Supervised | Postdoctoral Research Associates Supervised |
| --- | --- | --- |
| Beaty, E. C. | | L. C. Pitchford |
| Bender, P. L. | | D. R. Larden |
| Dunn, G. H. | J. Luine<br>S. Barlow<br>K. Timmer<br>R. Swanson<br>M. Blaser | A. Falk<br>D. Belić |
| Faller, J. E. | B. Rinker<br>M. Zumberge<br>P. Keyser<br>K. McLagen | |
| Gallagher, A. C. | J. Huennekens<br>H. Chatham<br>B. Robertson | W. Kamke<br>R. Dang |
| Gebbie, K. B. | W. B. Kint<br>J. G. Porter<br>L. J. November (with J. Toomre) | |
| Geltman, S. | S. Haan | |
| Hall, J. L. | L. Hollberg<br>M. Rayman<br>D. Meschede | T. Baer<br>(NRC)-P. Nachman<br>M. Hohenstatt |
| Hummer, D. G. | D. Carroll<br>Birte Christensen-Dalsgaard | D. C. Abbott<br>A. A. Kutepov (Exchange Visitor, Univ of Leningrad |

OTHER ITEMS OF INTEREST TO THE PANEL

Quantum Physics Division (525)

| Name | Graduate Students Supervised | Postdoctoral Research Associates Supervised |
|---|---|---|
| Leone, S. R. | D. Nesbitt<br>W. Pence<br>D. Guyer<br>T. Zwier<br>L. Kovalenko<br>M. Hale<br>(NSF Fellowship) C. Hamilton<br>J. Smedley | H. Hermann (DFG Fellowship)<br>(NRC)-S. Baughcum<br>(NRC)-F. Magnotta<br>B. Koffend<br>J. Weisshaar (Nobel Laureate Signature Award Winner)<br>V. Bierbaum (25%)<br>(NRC)-M. Duncan<br>L. Huwel (Max Planck Fellowship) |
| Linsky, J. L. | P. Bornmann<br>N. Marstad<br>M. Schindler<br>M. Giampapa (Univ. of Arizona)<br>D. Zarro (Australian National Observatory) | F. Walter<br>R. Stencel<br>T. Simon<br>K. Eriksson<br>R. Hammer |
| Norcross, D. W. | | N. Padial<br>A. Pradhan<br>R. Christensen |
| Phelps, A. V. | S. Yoshida (Kieo Univ., Yokohama, Japan) | M. A. Islam<br>C. Yamabe<br>P. A. Vicharelli<br>S. Buckman |
| Smith, S. J. | D. Meschede | D. Elliott<br>R. Roy |

# OTHER ITEMS OF INTEREST TO THE PANEL

## Quantum Physics Division (525)

| Name | Courses Taught at the University of Colorado |
|---|---|
| Bender, P. L. | Physics 451 - Modem Optics (Fall 1981) |
| Faller, J. | Experimental Physics (2 weeks)--with Bartlett and Ristinen) |
| Geltman, S. | Physics 203 (Recitation) (Fall 1980) |
| Hall, J. L. | Topics in Modern Optics (Fall 1980) |
| Leone, S. R. | 550 Chemical Dynamics (Fall 1980) |
| Linsky, J. L. | AG 650 - Stellar Winds and Coronae (Spring 1981) |
| Smith, S. J. | Physics 331 (Spring 1982) |
| | **Course Taught Elsewhere** |
| Leone, S. R. | Modern Optics (short course at the University of Utah, Fall 1981) |

### Item of Interest to the Panel

S. R. Leone was promoted to full Professor Adjoint, Department of Chemistry, University of Colorado.

## OTHER ITEMS OF INTEREST TO THE PANEL

### Quantum Physics Division (525)

| Name | Scientists Working at JILA on Sabbatical or Other Leave (other than visiting Fellows) |
|---|---|
| Beaty, E. | W. Allis (MIT - Cambridge, Massachusetts) |
| | J. A. Rees (The University of Liverpool, England) |
| Conti, P. & Linsky, J. | G. Wallerstein (University of Washington - Seattle, Washington) |
| Conti, P. | L. Wilson (University College London, England) |
| Cooper, J. | J. Dufty (University of Florida - Gainesville, Florida) |
| Gallagher, A. C. | B. Stumpf (Universität des Saarlandes, West Germany) |
| | B. Kamke (University of Marburg, West Germany) |
| | N. Bras (University of Paris) |
| Geltman, S. | M. J. Conneely (University College - Galway, Ireland) |
| Hummer, D. G. & Norcross, D. W. | B. Christensen-Dalsgaard (University of Aarhus, Denmark) |
| Leone, S. | H. Hermann (University of Kaiserslautern, West Germany) |
| | L. Huwel (Max-Planck-Institut für Strömungsforschung)(Fellowship and Award Winner) |
| Lineberger, C. | J. B. Peel (LaTrobe University, Australia) |
| Norcross, D. | N. Padial (Inst. Fisica, Campinas, Brazil) |
| Toomre, J. | D. Gough (Inst. of Theoretical Astronomy, Cambridge, England) |
| | J. P. Zahn (Obesrvatoire de Nice, France) |

## OTHER ITEMS OF INTEREST TO THE PANEL

### Quantum Physics Division (525)

### Research Fellowship for Teachers

Over the years JILA scientists have sought means to make a scientific career attractive to talented individuals who are women or of minority origin. There have been laudible individual efforts including lecturing at schools and teaching summer classes of minority students. Two years ago, it was decided that JILA should do something on an institutional basis, and a separate Research Fellowship for Teachers was established. The JILA Research Fellowship for Teachers is supported by the National Bureau of Standards through a grant to the University of Colorado. It is available for teachers who, in their home colleges or universities are in a position to influence minority and women students towards careers in the physical sciences. There are no set duties or assignments associated with the Fellowship, similar to the Visiting Fellowship. Selection is based on scholarly achievement or promise, experience and interest in a field of science that will allow fruitful interaction with JILA scientists, and demonstrated ability to motivate their students toward careers in the physical sciences. The program provides facilities to recipients on sabbatical salaries and may provide full stipends for recipients without support from their home institution or other sources. Roundtrip transportation costs are paid for the recipients and their immediate families.

Funding for the program was obtained by taking $15 K from the Visiting Fellows Program, and an additional $15 K has been guaranteed, if needed, by the Personnel Management Board of NBS. The latter is to be used only in cases where backup is needed.

The first year (1980-81) Dr. Robert Bauman, Professor of Physics at the University of Alabama was chosen for the fellowship. His visit was very successful. His research with Alan Gallagher on silane discharges will be continued at Alabama. He gave lectures on overcoming learning barriers for underprivileged persons.

This year Dr. Ronald Mickens, Professor of Physics, Fisk University, Nashville, Tennessee. A theoretical physicist with broad interests, he has in the few weeks he's been in JILA already been very active.

Though the competition level for this fellowship has not been nearly as high as for the Visiting Fellowships, the quality of appointees has been very high, and all indicators point to success for the program.

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11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report summarizes research projects, measurement method development, calibration and data evaluation activities carried during Fiscal Year 1981 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)

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

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