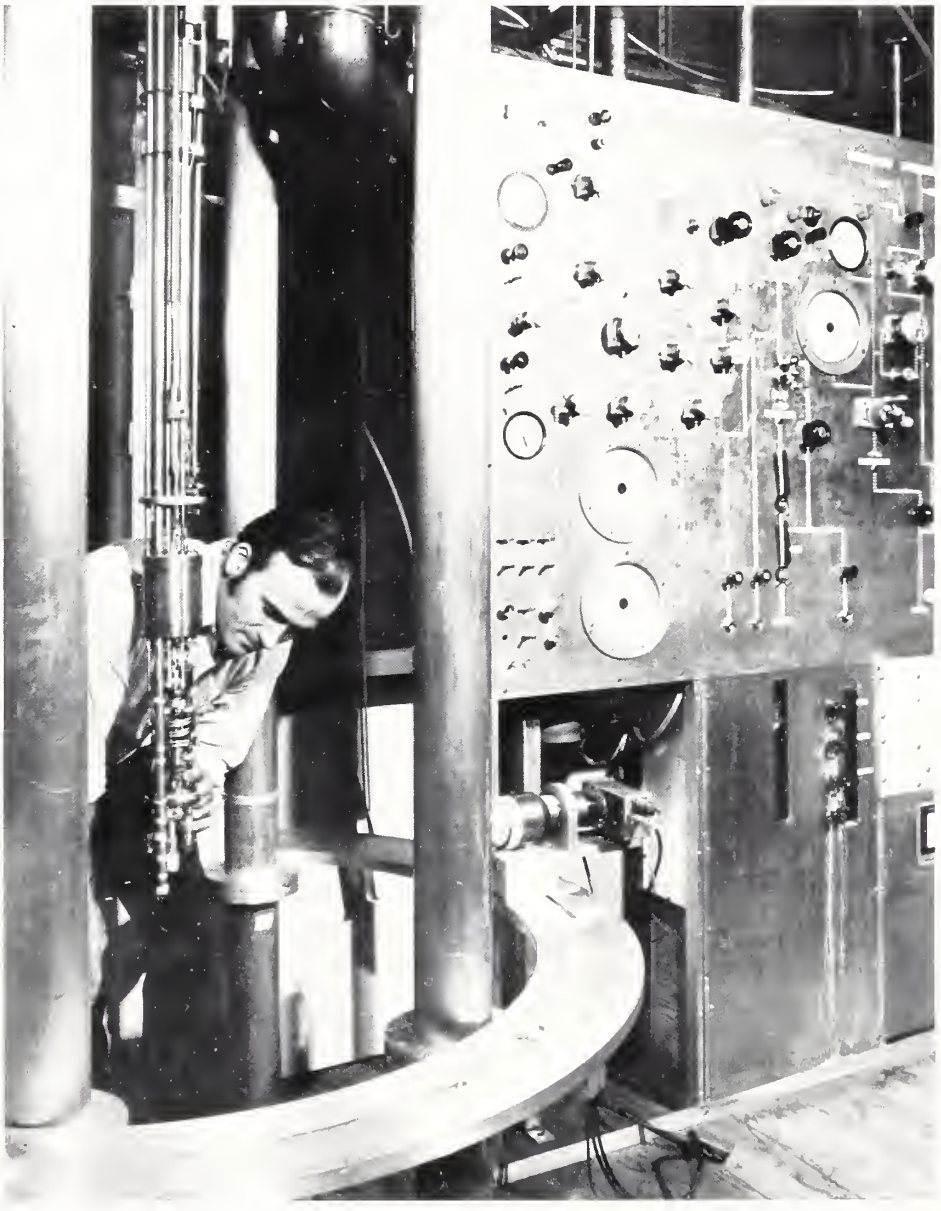
U.S. Department of Commerce

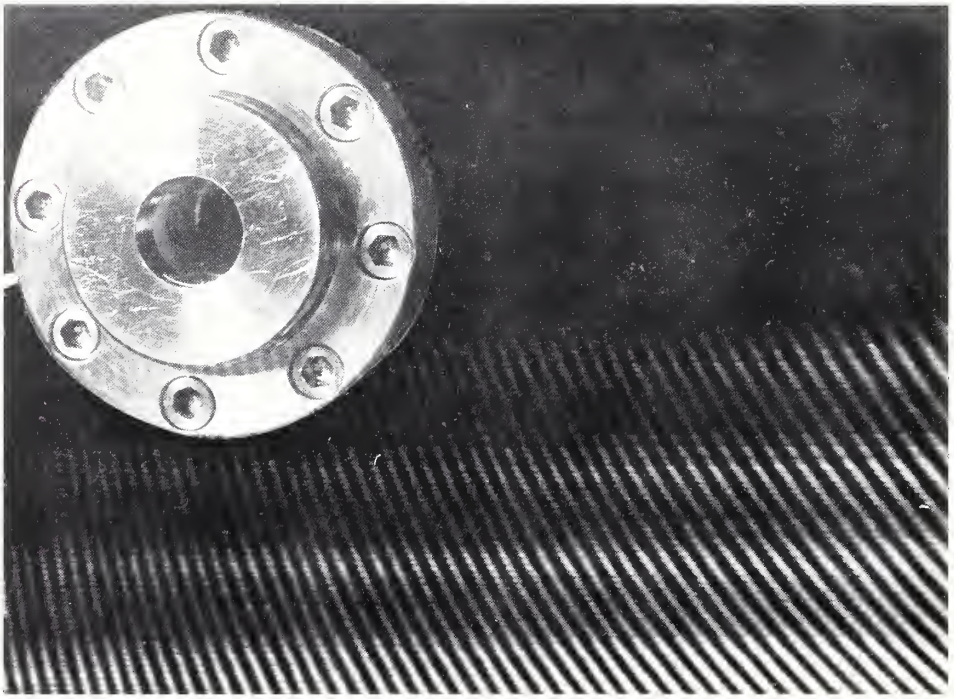
National Bureau of Standards
Institute for Basic Standards

NBS Heat Division:
an introduction



Contents

*This is now part of the Equation of State Section



Cover Photo: R. B. Dove mounting a research sample on a ^{3}He - ^{4}He dilution refrigerator.

Introduction: Since 1901, the National Bureau of Standards has fostered the scientific and technological development of our nation through its mandated responsibilities to develop, maintain and disseminate our national network of measurements and standards. As part of this mission, the Heat Division carries out research in the measurement of temperature, pressure, and humidity, and research in cryogenic physics, in the equation of state of materials and the techniques for producing critical thermodynamic data, and in statistical physics. The Division has the basic responsibility for establishing and improving units and standards for thermometry, pressure and vacuum, and humidity and moisture measurements; and for dissemination of these units and standards to science and industry through calibrations and other services.

This requires high-level *research* in physics and engineering, *development* of new measurement techniques and refinement of existing ones to meet new needs, *design and construction* of special instrumentation and standards for calibrating the standards of other laboratories, *calibrations* of such standards, *collaborations* with government agencies, universities, and industry, and *other services* related to these tasks. The unique NBS facilities and the knowledge and competence of its staff are available to provide calibration and a number of other services. This brochure is to introduce you to these services.

For further information
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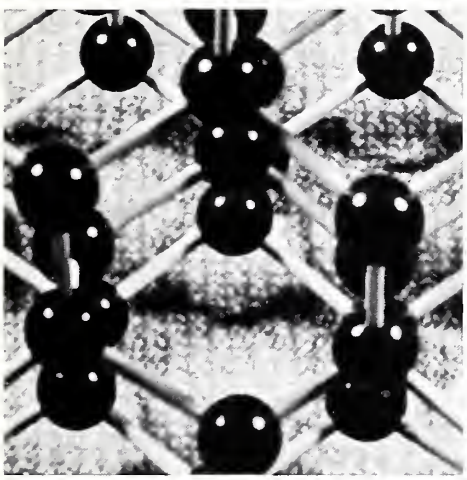


Division Services

Research and Development. Research in selected topics of physics and engineering and development of measurement methods are natural outgrowths of division activities. If special needs exist in those fields encompassed by the Heat Division, staff scientists and engineers and laboratory facilities may be of unique assistance. Similarly, NBS staff members can assist in solving special measurement or instrumentation problems and provide consultation on related problems. Often government agencies, universities or industry find that a collaborative effort between NBS scientists and those of their own institution is advantageous in furthering their own programs. Examples of such collaborative work can be found at the end of this brochure.

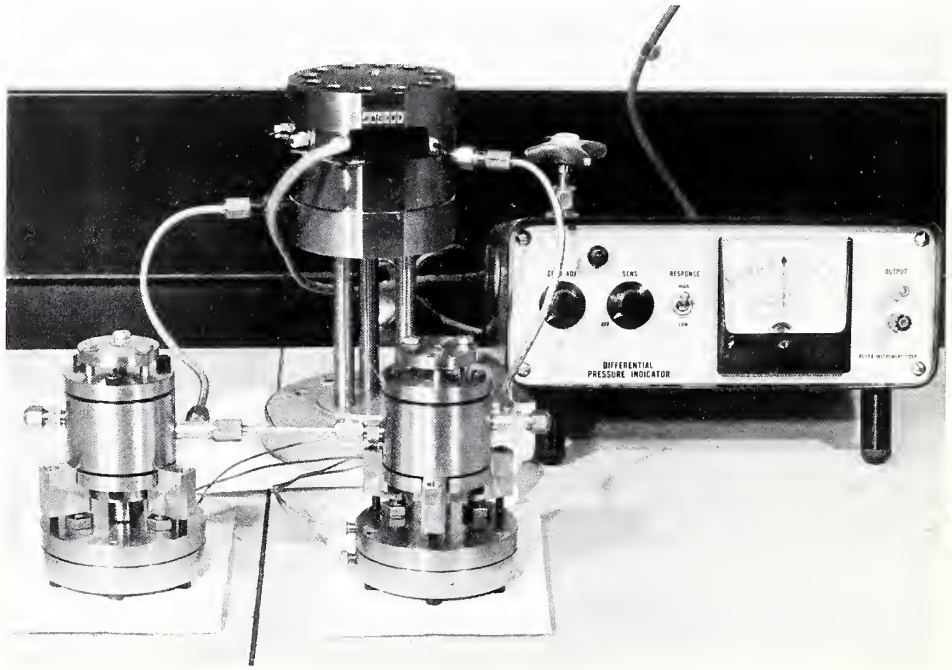
Calibrations. Most calibrations at normal accuracies and test conditions are done by well established techniques in accordance with fee schedules published in NBS Special Publication 250, *Calibration and Test Services of the National Bureau of Standards*. However, special calibrations under unusual conditions and/or at better-than-usual accuracies can often be made by special techniques on a cost-plus-overhead basis. Inquiries will be given prompt attention.

Measurement Assurance Program. A Measurement Assurance Program (MAP) is a new kind of NBS service to help other laboratories establish the accuracy of their realization of temperature and pressure and to verify the accuracy of their measurements using NBS capabilities. A MAP is tailored to the specific needs of the other laboratory. It generally involves the repeated transport of standards or standard instruments owned by NBS to another laboratory. The laboratory, by comparison calibration or other techniques, calibrates the NBS standards by its own techniques but following experimental or statistical designs suggested by NBS. The direct use of an NBS standard of known performance reduces the number of scale transfers required so that the realization of temperature or pressure at other laboratories can be established with higher accuracy than that which is obtained by relying only on the calibration of the other laboratory's standards at NBS. At the same time, because of the NBS statistical design, the state of statistical control and the limits of error of the measurement process are evaluated directly.

Design and Construction. NBS does not usually design or construct instrumentation and standards for others. However, it is authorized to do so under unusual circumstances when there are no commercial sources and when only limited numbers of items are involved. This is sometimes particularly advantageous for those needing new types of instrumentation or standards, especially for those who require state-of-the-art realization of the units.

Publications. NBS publishes the results of its research to aid others who may wish to use its developments and services. An annual summary of NBS publications may be found in the NBS Special Publication SP-305, *Publications of the National Bureau of Standards*. A representative list giving some of the recent publications of the Heat Division can be found with each description of the Division sections.

Industrial Research Associates. The Research Associate Program is a well established service of NBS. More than 60 research associates, generally appointed and paid by professional organizations or industry groups, are working in NBS laboratories on projects of mutual interest to the public and the sponsoring organizations. The associates usually work for 1- or 2-year periods, but longer terms are permissible. They have the use of the fine equipment in NBS laboratories and immediate and continuing access



Pressure gage comparator

to NBS staff members. Normally there are no overhead or other NBS charges except for expendable equipment and computer services, making this a real bargain for the public and the sponsoring group if a match of NBS and industry interests can be found.

Postdoctoral Fellowships. The NBS Postdoctoral Fellowship Program for recent doctoral graduates is administered by the National Academy of Sciences under a grant from NBS. Candidates are evaluated by the Academy.

Training Seminars. The Heat Division conducts seminars on its techniques for making accurate temperature and pressure measurements. These seminars, at the NBS Gaithersburg, Maryland site, are conducted annually or semi-annually as needed. The cost is borne by the attendees. Special seminars in greater depth and individual training at NBS can also be arranged.

Conferences and Meetings. The Heat Division has organized a variety of conferences and meetings on topics related to the interests of the Division. In some cases, either because the topic is of extremely broad interest or because of a mutual interest, the sponsorship of these conferences is shared with other organizations. Recent conferences and meetings include:

Symposium on Temperature. There have been five symposia on temperature in the United States since 1919. This series has attained international prominence for its discussion of thermometric research, technology and applications. The "Fifth Symposium on Temperature" was held in Washington and cosponsored by NBS in 1971, with the proceedings published as volume four of *Temperature, Its Measurement and Control In Science and Industry.*

Conference on the Burnett PVT Method. The conference was organized in response to a need for enhancing the potential of a particularly simple PVT method for producing equation-of-state measurements at the leading edge of the state of the art. Data reduction with this method is complex and a need existed for establishing the validity and possible equivalence of different approaches to data reduction. The meeting resulted in a more thorough description and analysis for this PVT method than had ever been done previously for any technique. The conference was held in 1969 at NBS.

Washington Area High Pressure Colloquium. In 1968 the Pressure and Vacuum Section organized the first of a series of annual colloquia which bring together scientists and engineers from the Washington area to discuss subjects related to high-pressure technology, physics and engineering. The last meeting, held at the University of Maryland in 1975, had more than 50 participants from Washington, D.C., and four neighboring states. The meetings promote the exchange of information on technical and experimental details and foster closer cooperation between various laboratories engaged in high-pressure research.

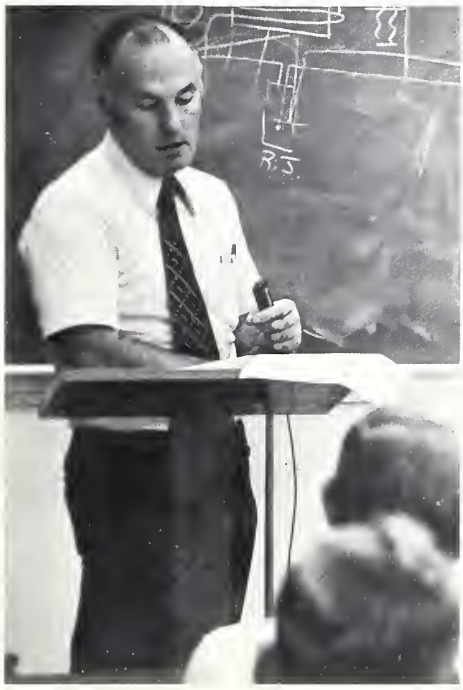
Annual Meeting on Topics in Statistical Mechanics. The Statistical Physics Section hosts an annual gathering of area scientists interested in statistical mechanics. This 1-day meeting, cosponsored by scientists at the University of Maryland, provides an effective way of furthering scientific discussion between members of the Washington, D.C., metropolitan area statistical mechanics community. The Fall 1975 meeting was primarily devoted to critical phenomena and the problems associated with reconciling theory and experiment in this active area. Over 60 people attended the sessions.

Heat Division Colloquium. Topics of particular interest to the Division are presented weekly by experts, either from NBS or elsewhere, in the field.

Upcoming conferences being planned are:

Joint NBS-ONR Symposium on Superconductivity. Prestigious scientists engaged in experimental or theoretical studies of superconductivity are invited to speak at NBS in order to promote greater exchange of information and to foster collaborations. The series features one speaker per month.

Conference on the Thermodynamic Properties of Fluid Mixtures. A research seminar on the thermodynamic properties of fluid mixtures will be sponsored by the Statistical Physics and Equation of State Sections. This seminar, planned for April of 1977 will address the prospects for developing accurate predictive capabilities for the thermodynamic properties of fluid mixtures. Interested scientists and engineers from industry, government and academia will participate in the program. The main objective of the seminar will be to clarify strategies to be employed in achieving a predictive capability useful to science and technology.



Lecture during Precision Temperature Measurement Seminar.

Division Structure and Programs

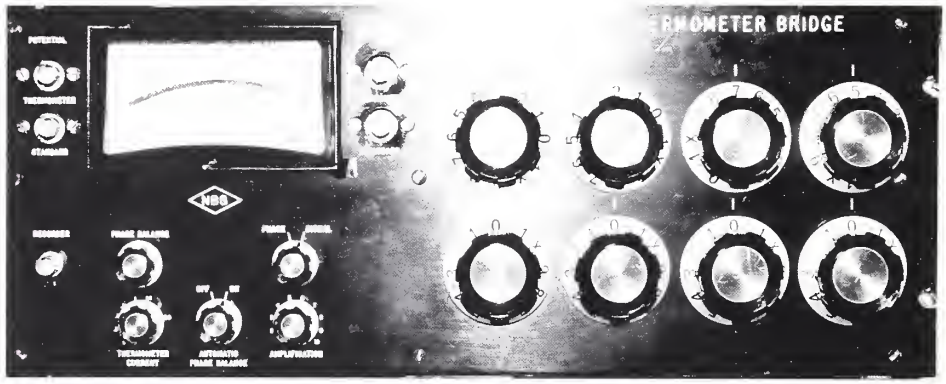
The work of the Heat Division is performed by six sections:

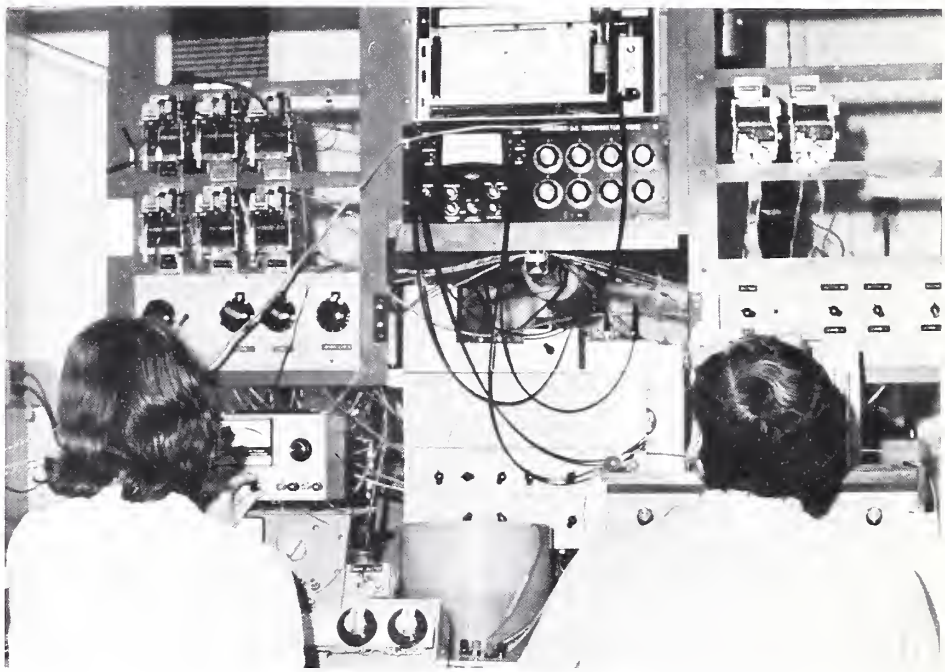
- Temperature
- Cryogenic Physics
- Pressure and Vacuum
- Equation of State
- Humidity
- Statistical Physics

Although nominally independent, there is strong interaction among the staff of the different Sections so that the full expertise of the entire Division, and, indeed, of the entire Bureau, may be brought to bear on any specific problem or in any particular activity. The activities, research interests, and unique and special features of the Sections are presented in abbreviated form below.

Temperature Section

Cutkosky ac ratio-transformer bridge designed for use with standard platinum resistance thermometers.





Sharrill Wood and Summerfield Tillett engaged in a study of the stability of thermistors.

Standards and Service Activities

Has sole responsibility in the U.S. for the realization and maintenance of the International Practical Temperature Scale (IPTS-68). From 14 K to 630°C, the scale is realized by calibrating platinum resistance thermometers of specified characteristics at certain thermometric fixed points. At other temperatures the scale is defined by employing specified equations to calculate values from the indications of the thermometers. In a similar manner, temperatures from 630°C to 1064°C are obtained from the use of platinum-10% rhodium/platinum thermocouples calibrated at specified temperatures and fixed points and interpolated according to specified equations.

Has responsibility for dissemination of the temperature scale (IPTS-68) to fulfill the temperature measurement needs of the country.

Offers calibration services for platinum resistance thermometers, thermocouples, liquid-in-glass thermometers, germanium resistance thermometers, and thermistors. Special calibrations can also be arranged.

Offers thermometry instruction; Annual Precision Thermometry Seminar; calibration laboratory courses for university students; individual laboratory instruction; and information center on thermometry and heat measurements.

Acts as expert consultant to standards groups, such as: American Society for Testing and Materials; American National Standards Institute; International Organization for Legal Metrology; Advisory Committee on Thermometry, General Conference on Weights and Measures; International Institute of Refrigeration; National Committee for Clinical Laboratory Standards; American Association of Clinical Chemists; and College of American Pathologists.

Instrumentation, Methodology and Other Development Work

Thermometric fixed points. These are reproducible equilibrium states of matter (such as the triple point of water) to which values of temperature are assigned. They may be employed as primary fixed points as part of the definition of the temperature scale or as secondary fixed points to assist in the calibration of secondary thermometers. The present range of interest is 0.5 K to 1337 K (1064°C).

Thermometry calibration methods.

New temperature sensor studies: high-temperature thermocouples (1000°C to 2200°C); precision high-temperature platinum resistance thermometers (to 1100°C); thermistors (-50°C to 200°C); and thin film thermometers (-20°C to 120°C).

Characterization of the properties of thermometers. Studies of the long term stability, effects of temperature cycling, self-heating, and the dynamic characteristics such as time response.

Manometry as applied to thermometry.

Ac bridges in thermometry.

Research

- Thermodynamic thermometry by:
  - Constant volume gas thermometry.
  - Speed of sound in helium gas.
  - Power ratio calorimetry of blackbody radiation.
- Thermal physics of thermocouple alloys.
- Melting and freezing of metals.
- Thermometric fixed points.
- Thermal physics of dielectric films.

Other Interests and Areas of Competence

- Calorimetry of metals and oxides at low temperatures.
- Superconductivity in pure metals.
- Solid-state thermometric fixed points.
- Thermal physics of refractory metals.
- Phase behavior of high purity metals.
- Electrical properties of insulators at high temperatures.
- Gas thermometry below 0°C.
- Vapor pressure of water.

Partial List of Thermometers Calibrated by Temperature Section

Platinum resistance thermometers	
Long stem	90 K to 900 K
Capsule	13.8 K to 500 K
Miniature	-50°C to 200°C (Approx.)
Thermocouples	
Fixed point calibrations	0°C to 1450°C
Comparison calibrations	-196°C to 2100°C
Liquid-in-glass thermometers	-196°C to 538°C
Germanium resistance thermometers	2 K to 20 K
Thermistors	-50°C to 200°C

Unique and Special Facilities

Ultra-high-vacuum/inert-gas high temperature furnace (2500°C at 1.3×10^{-6} Pa (10^{-8} torr).

Mercury manometer (total uncertainty 1.5 parts in 10^6 in pressure ranges 5×10^3 Pa to 1.1×10^5 Pa).

Blackbody radiation calorimeter.

High-accuracy (total uncertainty of 5 parts in 10^7) thermal expansion measurement apparatus operable over the temperature range -20°C to 1100°C.

Cutkosky ac ratio-transformer bridges (total uncertainty of 3 parts in 10^8 at full scale).

Special design Mueller type dc bridges for state-of-the-art dc resistance measurements.

Apparatus for realization of thermometric fixed points.

Section time-share minicomputer system for on-line experimental control and data logging.

Partial List of Representative Publications.

Burns, G. W. and Hurst, W. S., *Thermocouple thermometry,* in Temperature Measurement 1975, Editors: B. F. Billing and T. J. Quinn, pp. 144-161 (Conf. Series No. 26, The Institute for Physics, London and Bristol, 1975).

Cataland, G. and Plumb, H., *Fixed points: Superconductive transition temperatures of lead and indium,* Metrologia **11,** 161-163 (1975).

Furukawa, George T., *Investigation of freezing temperature of National Bureau of Standards aluminum standards,* J. Res. Nat. Bur. Stand. (U.S.) **78A,** No. 4, 477-495 (July-Aug. 1975).

Furukawa, George T., Reilly, Martin L., and Gallagher, John S., *Critical analysis of heat-capacity data and evaluation of thermodynamic properties of ruthenium, rhodium, palladium, iridium, and platinum from 0 to 300 K. A survey on the literature data on osmium,* Physical & Chemical Reference Data **3,** 1, 163-209 (1974).

Furukawa, George T., Riddle, John L. and Bigge, William R., *The International Practical Temperature Scale of 1968 in the region 13.81 K to 90.188 K as maintained at the National Bureau of Standards,* J. Res. Nat. Bur. Stand. (U.S.) **77A,** No. 3, 309-332 (May-June 1973).

Guildner, L. A., Johnson, D. P., and Jones, F. E., *Vapor pressure of water at Its triple point, J. Res. Nat. Bur. Stand. (U.S.)* **80A,** No. 3, 505-521 (May-June 1976).

Guildner, L. A. and Terrien, J., *Mercury absolute manometers* Chapter 4, Part 1 in *Experimental Thermodynamics,* Vol II, Experimental Thermodynamics of Non-Reacting Fluids, Editors: B. Le Neindre and B. Vodar (IUPAC, Butterworths, 1975).

Powell, Robert L., Hall, William J., Hyink, Clyde H., Jr., and Sparks, Larry L., and Burns, George W., Scroger, M. G. and Plumb, H. H., *Thermocouple reference tables based on the IPTS-68,* Nat. Bur. Stand. (U.S.) Monograph 125, 410 pages (March 1974).

Riddle, J. L., Furukawa, G. T., and Plumb, H. H., *Platinum resistance thermometry,* Nat. Bur. Stand. (U.S.) Monograph 126, 129 pages (April 1973).

Schooley, J. F., *Superconductive transition in cadmium,* J. Low Temp. Phys. **12,** 421 (1973).

Wise, Jacquelyn A., *Liquid-in-glass thermometry,* Nat. Bur. Stand. (U.S.) Monograph 150, 26 pages (Jan. 1976).

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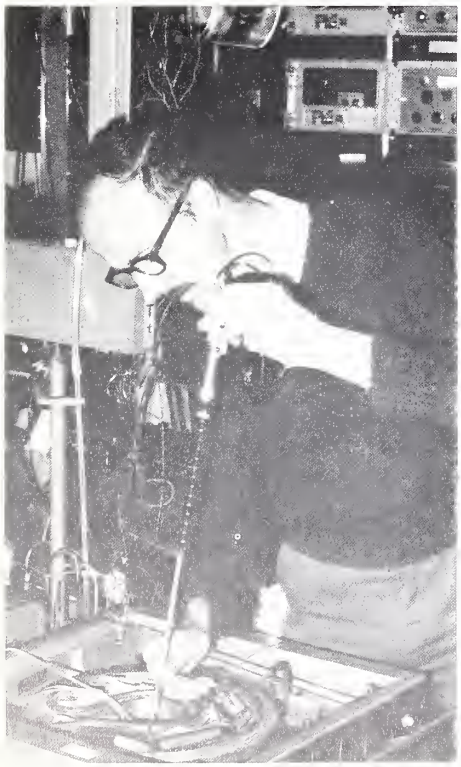
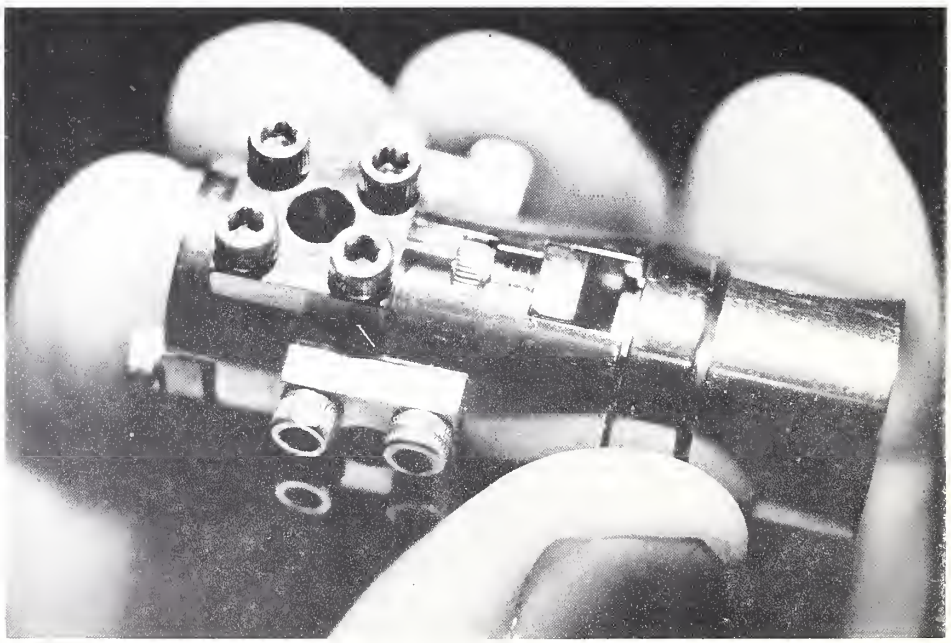


William Bigge installing a standard platinum resistance thermometer into a zinc freezing point cell.

Constant volume valve for the NBS high temperature gas thermometer.



Cryogenic Physics Section

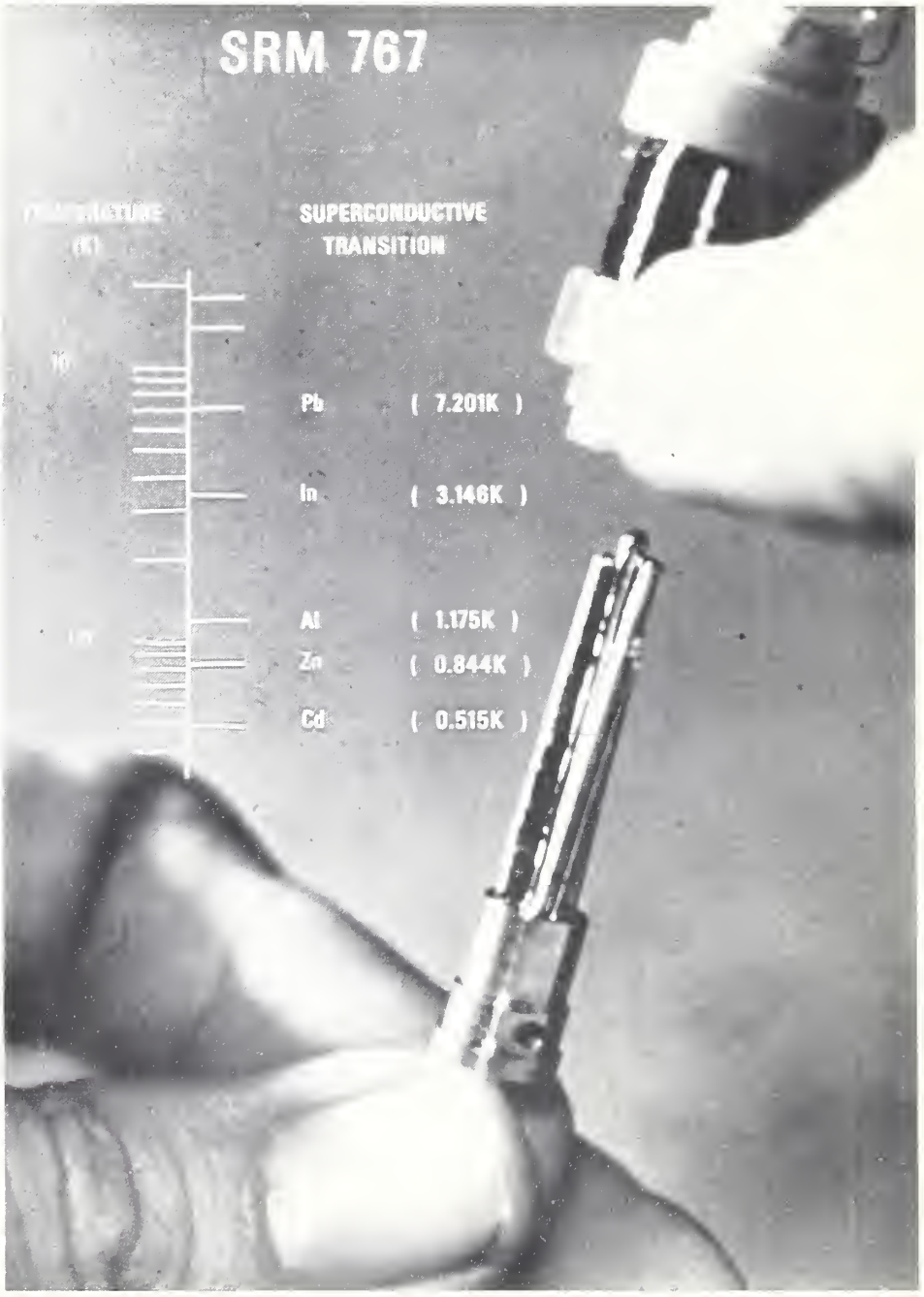
Standards and Service Activities

Develops and characterizes the physical laws which describe the properties of matter when maintained below 20 K.

Calibrates SRM 767. This device, issued by the Office of Standard Reference Materials and consisting of five specimens of different superconductors that are used as a set of five temperature reference standards, is calibrated via a temperature scale maintained at NBS.

Instrumentation, Methodology and Other Development Work

Superconductive temperature reference points. Improved temperature measurement below 1 K requires the development of materials which exhibit sharp and reproducible superconductive transitions for use as temperature fixed points. Several superconductors with transitions in the range 0.01K to 1K are being studied.



SRM 767: Five superconductors change the mutual inductance of the coil at five reference temperatures.

Cryogenic extension of the International Practical Temperature Scale. Several absolute thermometers are being compared in order to develop a temperature scale to extend the IPTS from its present limit of 13.8 K down to 0.01K.

Improved low-frequency nuclear magnetic resonance spectroscopy. The signal-to-noise of NMR signals at frequencies below 160 kHz are being enhanced by the use of superconductive devices known as SQUIDs.

Precision measurements of fundamental properties using radio-frequency oscillators. Low- temperature tunnel diode circuits with frequency stabilities exceeding one part per billion are used to convert position, pressure and temperature changes into frequency readout for very high-precision measurements which are easily processed by digital computers.

New cryogenic secondary thermometers. The Section is applying new techniques to develop secondary thermometers for the range 0.01K - 20 K.

Research

- Physical properties of superconductors.
- Characterization of primary thermometers:
  - Noise thermometry using Josephson Junctions.
  - Anisotropy of nuclear decay.
  - Nuclear magnetic resonance.
- Scattering of nuclear particles from oriented nuclei at low temperatures.
- Studies of magnetic phase transitions and other properties of magnetic insulators.

Other Interests and Areas of Competence

- Critical behavior near the λ-point of liquid He^4.
- Inelastic electronic tunneling spectroscopy to study surface physics, catalysis, etc.
- Physics of 1/f noise.
- Apply high-frequency SQUID (10 GHz) to study N^{14} nuclear quadrupole resonance in biological systems.
- The ac Josephson effect in superfluid He^4.
- Studies of nuclear magnetic resonance in oriented nuclei (NMR/ON technique).
- Study rare-earth magnetic systems using nuclear orientation techniques.

Unique and Special Facilities

Electron paramagnetic resonance spectrometry from 0.34 K to 300 K at X and K band frequencies.

Four dilution refrigeration facilities which are capable of maintaining temperatures from 0.01 K to 20 K for an indefinite period of time with a stability of ±0.1mK. Additional features which can be combined with these facilities are: providing a controlled dc magnetic field from 0.1 μT to 6T; working in a completely electromagnetically shielded environment for ultra-low noise measurements; conducting nuclear magnetic resonance spectrometry in either pulsed or continuous wave modes; measurement of physical properties from 0Hz to 10GHz.

An apparatus used to measure heat capacity with high precision from 0.1 K to 30 K.

^3He-^4He dilution refrigerator. Bruce Dove makes final tests before sealing cryostat for an experiment to be done at very near (0.01K) absolute zero.

Magnetic cooling (adiabatic demagnetization) installation.

Experts of national or international reputation in: nuclear magnetic resonance; nuclear quadrupole resonance; noise spectra; tunnel diode oscillators; oriented nuclei at low temperatures; superconductivity; and cryothermometry.

Partial List of Representative Publications

Cataland, G., Hudson, R. P., Mangum, B. W., Marshak, H., Plumb, H. H., Schooley, J. F., Soulen, R. J., Jr., and Utton, D. B., *NBS cryogenic thermometry and the proposed cryogenic extension of the IPTS,* Nat. Bur. Stand. (U.S.), Tech. Note 830, 32 pages (May 1974).

Hudson, R. P., Marshak, H., Soulen, R. J., Jr., and Utton, D. B., Review paper: *Recent advances in thermometry below 300 mK,* J. Low Temp. Phys. **20,** No. 1/2, 1-102 (July 1975).

Marshak, H., and Soulen, R. J., Jr., *The temperature scale defined by ^{60}Co γ-ray anisotropy and noise thermometry,* Low Temperature Physics-LT 13, Vol. 4, Editors: K. D. Timmerhaus, W. J. O'Sullivan, and E. F. Hammel, pp. 498-502 (Plenum Publishing Corp., New York, New York, 1974).

Meijer, Paul H. E., and Niemeijer, Th., *Quantum-mechanical approximation to the ground state of cerous magnesium nitrate,* Phys. Rev. **B11,** No. 7, 2612-2623 (April 1, 1975).

Schooley, J. F., *Enhancement Effects,* Science and Technology of Superconductivity, Vol. I, Editors: W. D. Gregory, W. N. Matthews, Jr. and E. A. Edelsack, pp. 405-428 (Plenum Press, New York, New York, 1973).

Schooley, J. F., Soulen, R. J., Jr., and Evans, G. A., Jr., *Preparation and use of superconductive fixed point devices, SRM 767,* Nat. Bur. Stand. (U.S.), Spec. Publ. 260-44, 35 pages (Dec. 1972).

Soulen, R. J. and Finnegan, T. F., *A microwave resistive SQUID for noise thermometry,* Révue de Physiqué Appliquée **9,** pp. 305-307 (Jan. 1974)..

Utton, D. B., *Proton spin-lattice relaxation in cerous magnesium nitrate hydrate,* J. Chem. Phys. **62,** No. 2, 670-674 (Jan. 15, 1975).

Utton, D. B., Soulen, R. J., Jr., and Marshak, H., *Intercomparison of temperature scales using low transition-temperature superconductors,* 14th International Conference on Low Temperature Physics, pp. 76-79 (American Elsevier Publishing Co., New York, New York, 1975).

Wong, C. Y., Tamura, T. Marshak, H., and Langsford, H., *Effects of nuclear collectivity on the total neutron cross section,* Particles Nucl. **4,** 163-174 (1972).

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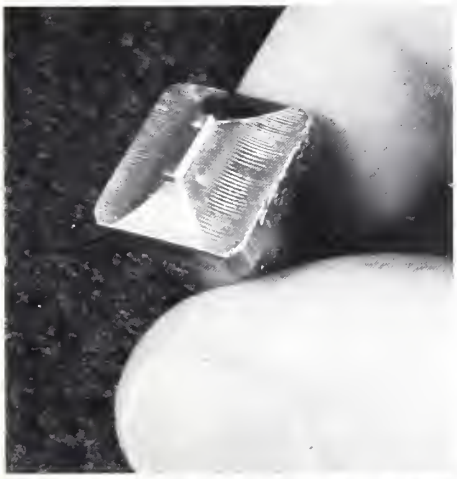
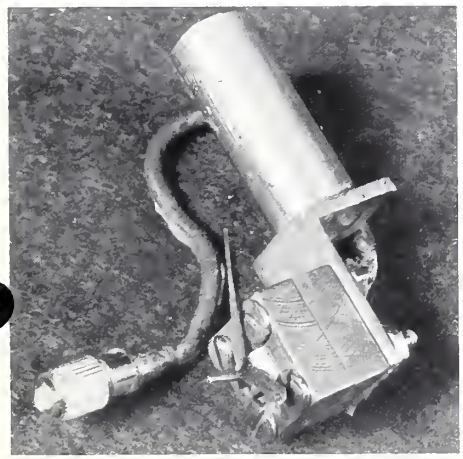
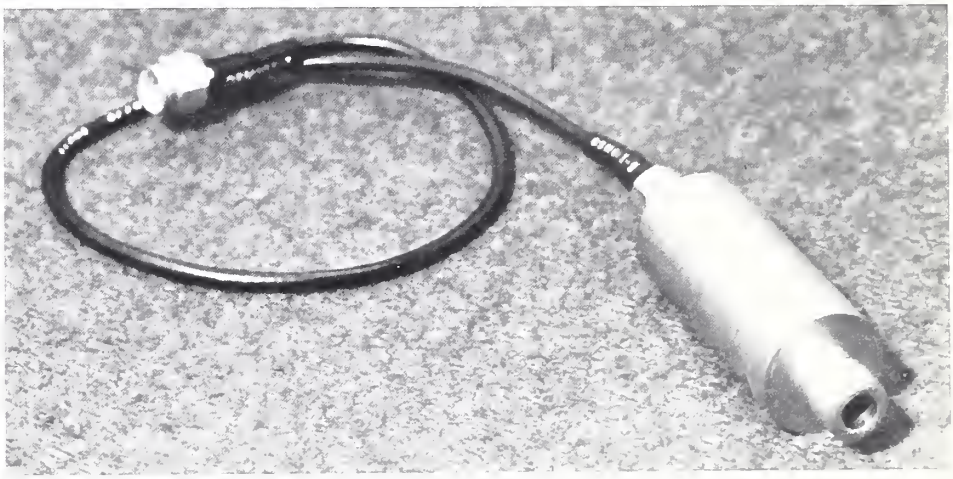


^{60}Co nuclear orientation thermometer that is used to define a temperature scale from 0.01K to 0.05K.



Noise thermometer that is used to define a temperature scale from 0.01K to 10K.



An ultraminiature gas thermometer complete with tunnel diode oscillator readout.

Pressure and Vacuum Section

Standards and Service Activities

Primary pressure standards. Mercury manometers and piston gages from 1 Pa to 5 GPa.

Calibration service. Provided for a large variety of instruments over the range of 1 Pa to 0.7 GPa.

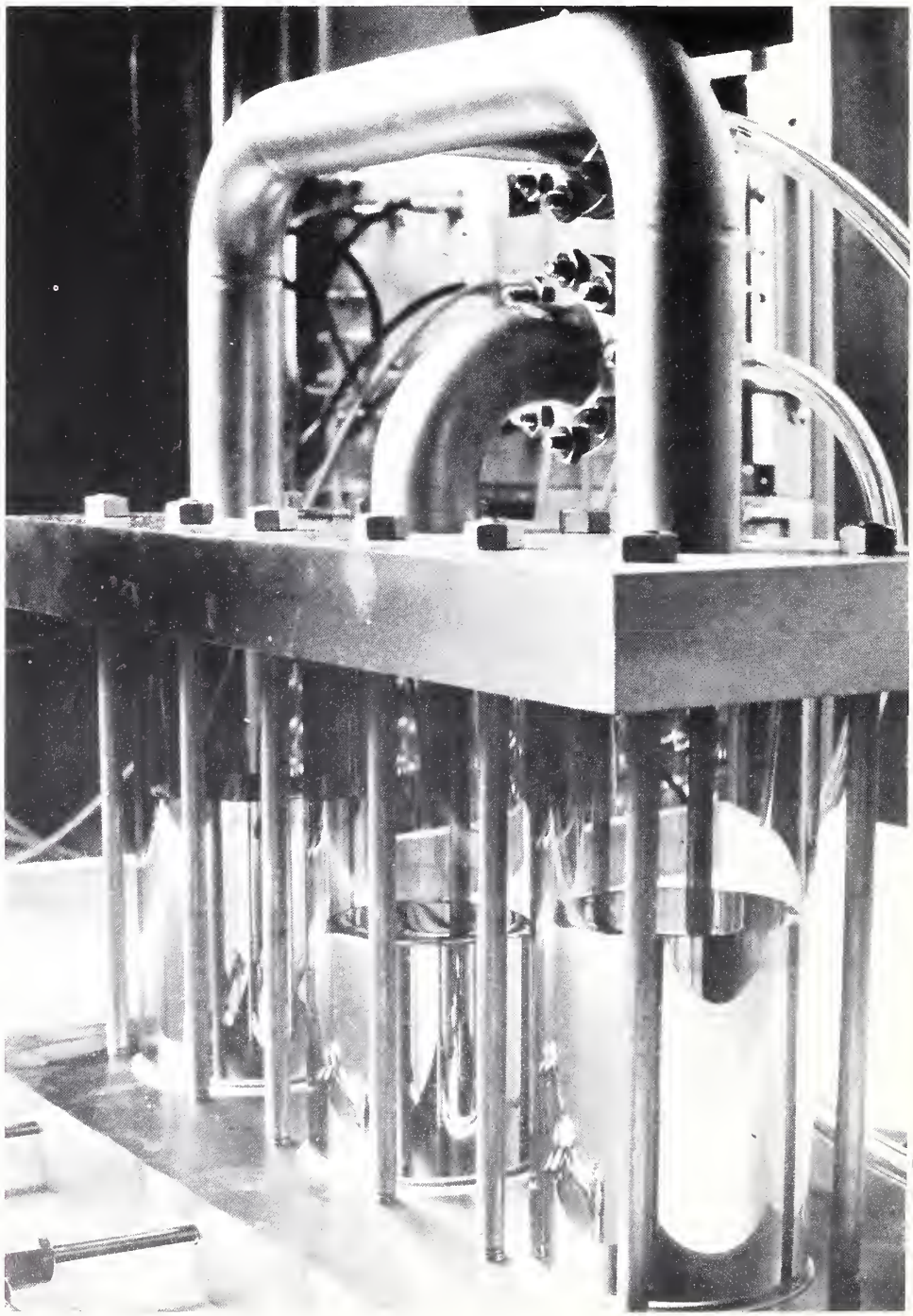
Training courses. Pressure measurement techniques for the personnel of standards laboratories.

Data evaluation. A data evaluation service, using NBS-developed programs.

Pressure transducer tests. Investigation of long-term pressure transducer performance is provided as a service.

Consultation. Consultation on all matters of pressure measurements.

Acts as expert consultant to groups such as: Instrument Society of America and American Society of Mechanical Engineers.



Ultrasonic interferometer manometer.

Instrumentation, Methodology and Development Work

Development of low-pressure instruments. Infrared and ultrasonic interferometer manometers for atmospheric to medium vacuum range.

Development of pressure transducers. Capacitance and ultrasonic interferometric measurements on selected materials for use as pressure transducers (2.5 GPa to 5 GPa range).

Development of a new generation of controlled clearance piston gages.

Development of transfer standards; Measurement Assurance Programs; and documentary standards and instruction manuals.

Research

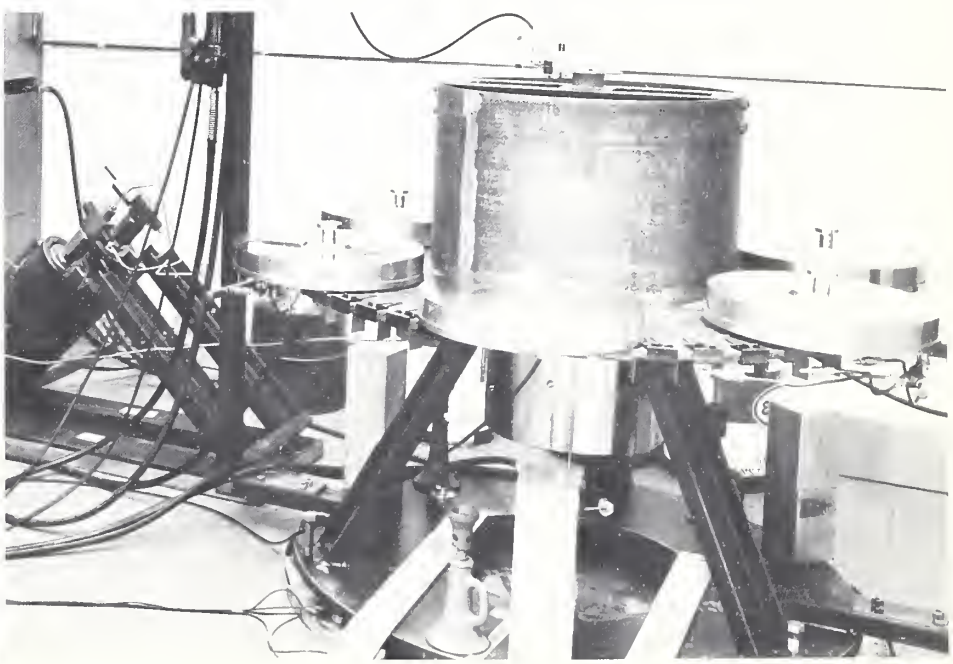
- Fixed points on the Pressure Scale (Pressure fixed points).
  Solid and solid-liquid phase transitions.
  Melting line of mercury to 700 MPa.
- Pressure transducers.
  Elastic and dielectric properties of solids as a function of pressure and temperature.
  Speed of sound in mercury to a precision of 6 parts in 10^6.
  Speed of sound in alcohol-water mixtures and highly reactive liquid propellants.
- Generation of precise gaseous mixtures.
  Mixtures of standard reference quality with the use of the ultrasonic manometer.
- Pressure Scale.
  Based on the equation of state of a suitable material.
- Metastable states and phase transitions.
- Rapidly changing temperature and pressure.
  To characterize the conditions of coolant accidents in reactors;.
  High Reynolds number wind tunnels;
  Space vehicles;
  Propellants and explosives.

Other Interests and Areas of Competence

- Universal Gas Constant.
  Accurate determination of the constant using a laser interferometer manometer.
- Optical diffraction coefficients of gases.

Dead-weight loaded piston gage.

Robert Driver performing a pressure transducer calibration.



Controlled clearance piston gage for pressure calibrations up to 3 GPa

Unique and Special Facilities

High pressure generators. Three generators up to 5 GPa at temperatures down to 20K.

Partial List of Representative Publications

Angel, William T., and Bean, Vern E., *A tracking pulsed ultrasonic interferometer,* Rev. Sci. Instr. **46,** 533-535 (1975).

Heydemann, Peter L. M., *Pressure measurements and services at NBS,* Proc. Fluid Power Testing Symposium, Milwaukee (1976).

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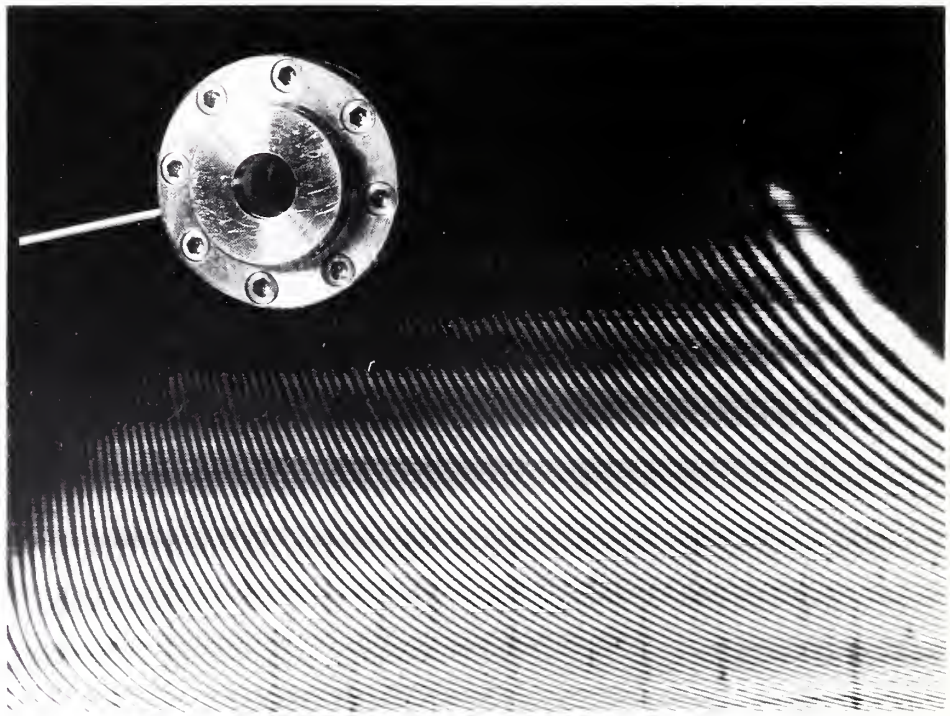
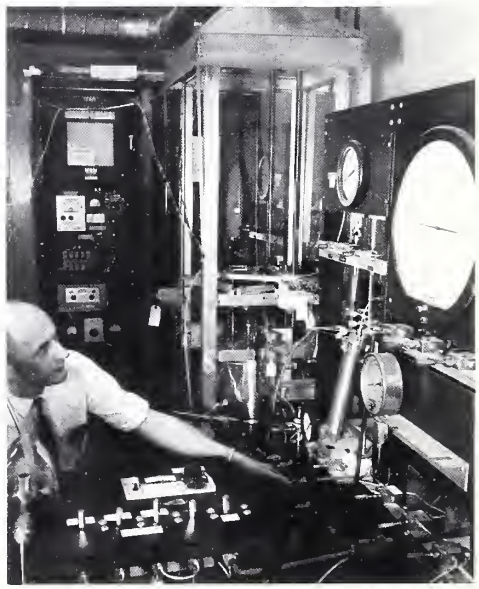


Gravity induces a density gradient in a pure fluid when it is at its critical point. An accurate equation of state can then be inferred from the diffraction pattern resulting when a laser beam is passed through the fluid.



With extreme accuracy, J. Hastings measures the relationship connecting pressure, volume and temperature for ethylene.

Standards and Services Activities

Develops measurement techniques and carries out measurements with an accuracy and precision at the realization state of the art of the basic units (especially temperature, pressure and density) to produce those thermodynamic data which are of primary national importance and which are not available elsewhere.

Develops theoretical models and methods for the application of such models to the description and prediction of thermodynamic data of national importance.

Acts as expert consultants to groups such as: International Advisory Board on the Properties of Steam; Executive Board on the Properties of Steam of the American Society of Mechanical Engineers; Office of Standard Reference Data; Commission on Thermodynamics and Thermochemistry of the International Union of Pure and Applied Chemistry; and an industrial group of ethylene producers.

Instrumentation, Methodology and Other Development Work

Demands for accurate thermodynamic data can be expected to grow rapidly over the next decade because of the growing demands for efficient energy production and utilization. Optical methods are being developed for taking such data more rapidly than present methods allow. Methods for the rapid determination of pressure are also being developed.

Apparatus has been developed for making PVT measurements at the state of the art in accuracy.

A rapid, simple, yet highly accurate means for the measurement of critical point parameters has been developed.

A thermostat capable of stability of 10^{-5}°C over the range 0°C to 50°C was developed.

An apparatus capable of very precise measurements of liquid densities has been developed and applied to several problems.

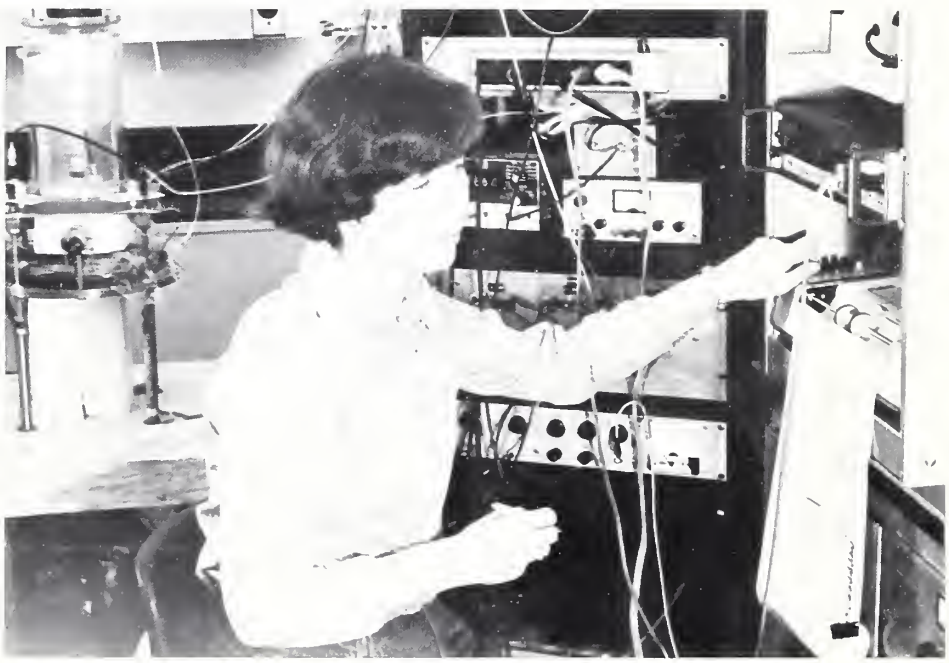
A computer program for simulating the behavior of a solid under precisely controlled conditions has been developed and applied to the problems of solids shocked by heat and/or mechanical pulses.

Research

- Very accurate measurement and description of anomalous behavior in the vicinity of critical points.
- Statistical and analytical problems associated with the development of multiparameter equations of state for the description of fluid systems.
- Development of methods for the detailed descriptions of the equations of state of fluid mixtures including phase equilibrium properties.
- Development of simple yet accurate equations of state for use in extrapolations of descriptions of fluid systems of industrial importance.
- Studies of the behavior of complex reacting fluid mixtures at high temperatures and pressures.
- Atomistic studies of the behavior of solids under conditions of very strong mechanical and/or thermal shock.

Other Interests and Areas of Competence

- Accurate measurements of the properties of fluid mixtures, sufficient in extent to be adequate for the task of producing theoretical models for their description.
- Studies of intermolecular forces--a subject of considerable importance in the development of molecular methods for the description and prediction of the thermodynamic and transport properties of fluid systems.
- A concerted effort for the development of rapid yet accurate methods for making PVT measurements.
- Development of theoretical models for describing fluid thermodynamic properties.
- Development of practical equations of state of solids with molecular bases.
- Extensive molecular dynamical studies of properties of solids as functions of carefully controlled microscopic properties.
- Accurate automated calorimetric measurements.
- The precise measurements of the dielectric and optical properties of fluids as functions of density and temperature.



Using a magnetic levitation method, Dr. Sandra Greer measures the coexisting densities of liquid mixtures.

Unique and Special Facilities

PVT apparatus with a relative imprecision not exceeding 1×10^{-4} in density in the temperature range of 0°C to 300°C.

Liquid density apparatus precise within 5 ppm and capable of measurements in individual liquid phases in heterogeneous liquid systems.

Vapor pressure apparatus capable of precisions for temperature within 1 mK and pressures within 0.001 atm for the range -70°C to 300°C.

Apparatus for the measurement of critical parameters of pure fluids for the range -70°C to 100°C with millikelvin temperature and +0.25% density total uncertainties (estimated).

Apparatus for very precise measurements of PVT properties near fluid critical points for the range -70°C to 100°C.

Ultra stable (microkelvin) thermostat for the range 0°C through 80°C.

Computer programs for studying the behavior of highly anharmonic solids under both equilibrium and transient conditions.

14 Computer programs for calculating the properties of reacting gaseous mixtures to very high (15,000K) temperatures and very high ($3\rho_c$) densities.

Partial List of Representative Publications

Greer, Sandra C., Block, Thomas E., and Knobler, Charles J., *Concentration gradients in nitroethane +3-methylpentane near the liquid-liquid critical solution point,* Phys. Rev. Lett. **34,** 250 (1975).

Haar, Lester, and Gallagher, John, *Thermodynamic properties for ammonia,* J. Res. Nat. Bur. Stand. (U.S.), in review.

Hocken, R., Horowitz, M., and Greer, Sandra C., *A critical anomaly in the dielectric constant of a nonpolar fluid,* Phys. Rev. Lett. **37,** No. 15 964-967 (1976).

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Moldover, M. R., *Visual observation of the critical temperature and density; CO_2 and C_2H_4,* J. Chem. Phys. **61,** No. 5, 1766-1778 (Sept. 1, 1974).

Sengers, J. M. H. Levelt, *From van der Waals' equation to the scaling laws,* Van der Waals' Centennial issue of Physica. Physica **73,** 73-106 (1974).

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Tsai, D. H. and MacDonald, R. A., *Heat pulse propagation in a crystal: A molecular dynamical calculation,* Solid State Commun. **14,** No. 11, 1269-1273 (1974).

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Waxman, M., Davis, H. A., and Hastings, J. R., *A new determination of the second virial coefficient of carbon dioxide at temperatures between 0°C and 150°C, and an evaluation of its reliability,* Proceedings of the Sixth Symposium on Thermophysical Properties, edited by P. Liley (ASME, New York, 1973).

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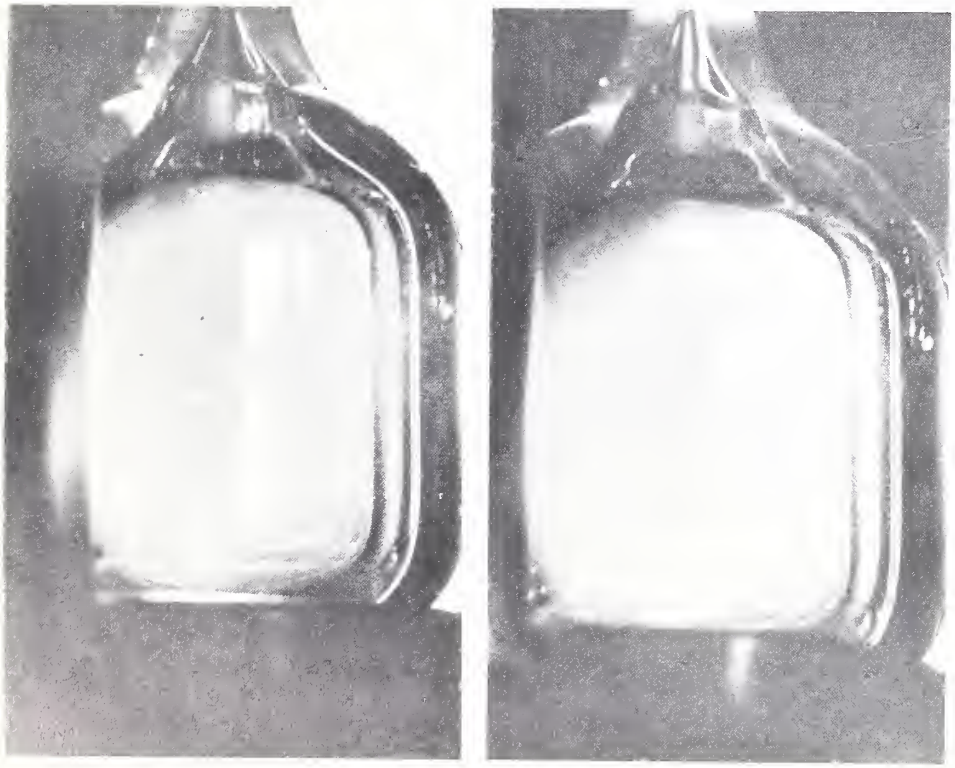

The location of the critical point is established through the disappearance of the fluid meniscus at the center of the cell. This is observed as the disappearance of laser beam reflection as shown. The temperature difference between the cell on the left and that on the right was 0.8mK.

Humidity Section*

*This is now part of the Equation of State Section

Standards and Service Activities

Primary humidity standards. Gravimetric hygrometer measures the mass of water vapor per unit mass of dry gas.

Calibration service. Calibrates humidity instruments and sensors over the range of parts per billion to parts per hundred (-70°C to +80°C frost/dew points).

Test facilities. Generators and associated equipment for testing humidity instruments and sensors over a wide range of ambient temperatures and pressures.

Reference methods for moisture measurement in grain. Karl Fischer and oven-drying methods.

Acts as member and expert consultant to groups such as: American Society for Testing and Materials Committee D22, Methods of Sampling and Analysis of Atmospheres; American Society for Testing and Materials Sub-Committee D22.11, Meteorological Measurements; International Standards Organization, TC/125, Enclosures and Conditions for Testing; and Interagency Coordinating Council for Water-Data Acquisition Methods Technical Working Group 10 on Hydrometeorological Methods.

Instrumentation, Methodology and Other Development Work

Development of humidity measuring instruments. Development of transfer standards and field instruments. Examples: Adiabatic saturation psychrometer, pneumatic bridge hygrometer and microwave hygrometer.

Development of specialized equipment. Example: Multiple-chamber humidity apparatus for use in microbiological studies.

Research

- Properties and constants of water vapor and vapor-gas mixtures. Examples: Vapor pressure of water, enhancement of water vapor in air and cross virial coefficients of water vapor-gas mixtures.

James Little mounting humidity sensors in gold-plated test chamber of NBS low frost-point generator for a calibration run.

Other Interests and Areas of Competence

- Vapor pressure of ice and supercooled water.
- Virial coefficients for water below 100°C.
- Humidity measurement techniques. In the parts per billion range and above 30 parts per hundred range.
- Fixed points for humidity. Chemical systems capable of controlling humidity such as saturated salt solutions.
- Humidity calibration techniques at ambient pressures above 0.2 MPa.
- Humidity calibration techniques at ambient temperature above 90°C.
- Humidity instrument response time measurement equipment.

Unique and Special Facilities

Low frost-point generator with the following capabilities: Gas streams with frost points from -100°C to -20°C; ambient pressures from 500 Pa to 3 MPa; any inert carrier gas; and ambient temperatures from -100°C to 25°C.

Two-pressure humidity generator with the following capabilities: Gas streams with dew/frost points from -70°C to +80°C; ambient pressures from 500 Pa to 0.2 MPa; gas flows from 0.03 to 0.3 m^3/min.; and ambient temperatures from -60°C to +80°C.

Minicomputer. Retrieval and analysis of large quantities of data.

Partial List of Representative Publications

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Greenspan, Lewis, *Low frost-point humidity generator,* J. Res. NBS (U.S.) **77A,** 671-677 (1973).

Guildner, L. A. Johnson, D. P. and Jones, F. E., *Vapor pressure of water at its triple point: Highly accurate value,* Science, **191,** 1261 (1976).

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Wexler, Arnold, *A study of the national humidity and moisture measurement system, NBSIR 75-933,* (1975).

Wexler, Arnold and Greenspan, Lewis, *Vapor pressure equation for water in the range 0°C to 100°C,* J. Res. NBS (U.S.) **75A,** 213-230 (1971).

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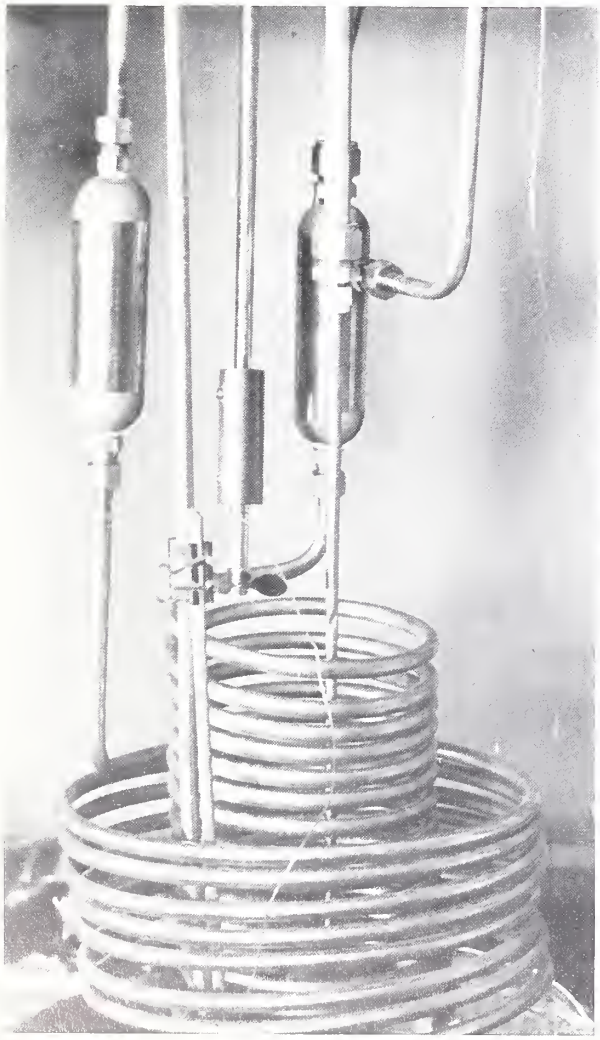
The heat exchanger and saturator units of the NBS low frost-point generator. In operation the inner coil is coated with a film of ice.



James Little installing an instrument for test and calibration in the NBS two-pressure humidity generator.

Statistical Physics Section

Service Activities

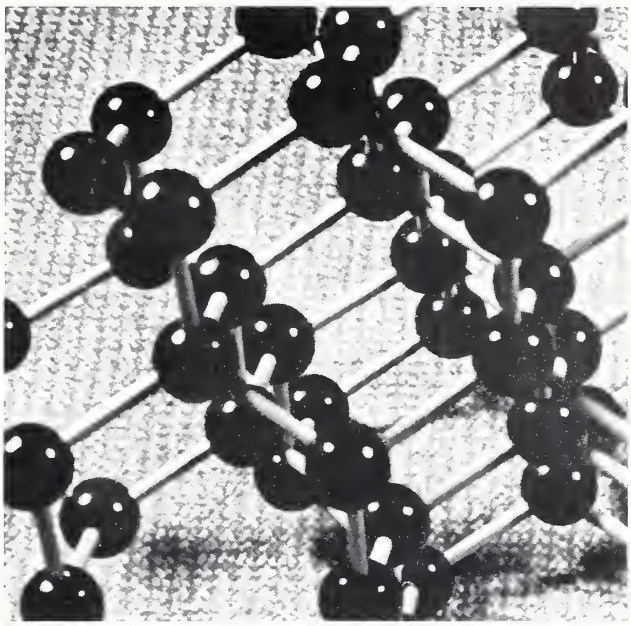
Provides theoretical support to other sections of the Heat Division, including research to assist exploratory studies.

Research

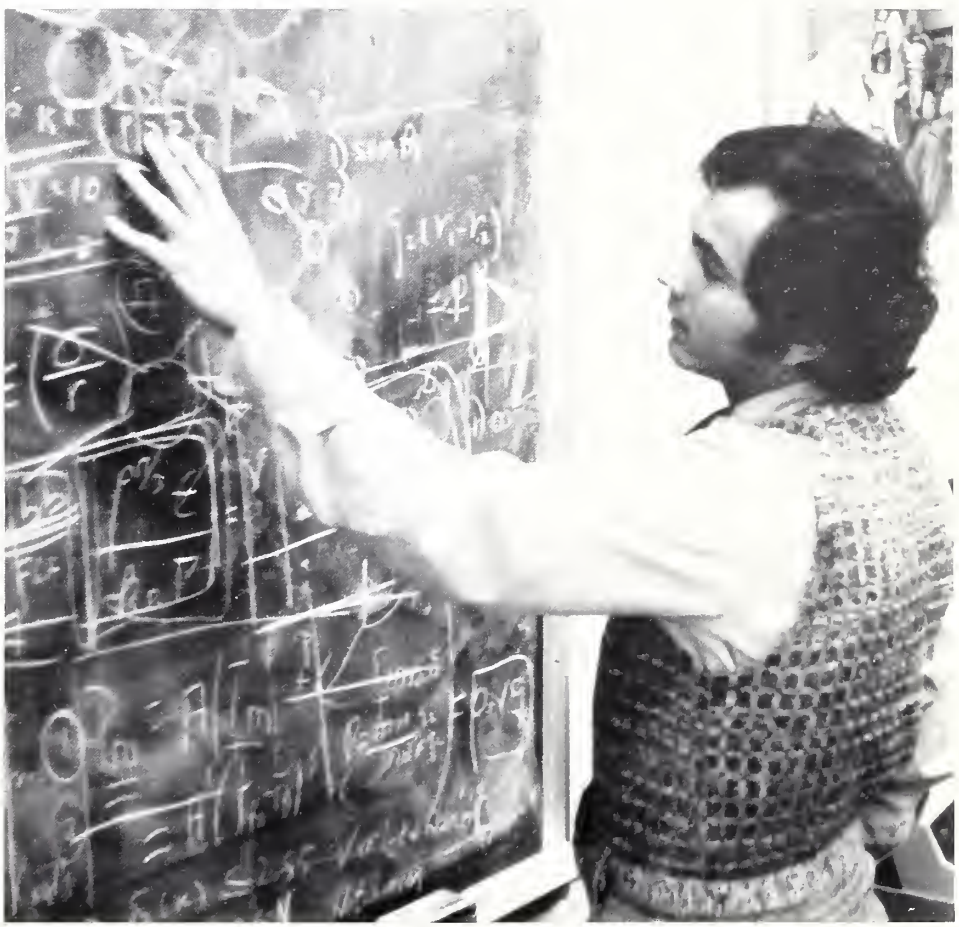
- Studies of liquids, rare gases and metals.
- Melting-freezing phase transitions.
- Metastable states.
- Fluctuations with emphasis on fluids.
- Critical phenomena and second order phase transitions.
- Non-linear transport processes.

Other Interests and Areas of Competence

- Equation of state of solids.
- Theories of binary liquid mixtures.
- Theories of 1/f or flicker noise.



Symmetry plays a central role in modern theories of condensed matter.



Dr. Harold Raveché at work investigating the symmetry features of thermodynamically metastable states.

Partial List of Representative Publications

Raveché, H. J. Mountain, R. D. and Street, W. B., *Freezing and melting properties of the Lennard-Jones system,* J. Chem. Phys. **61,** 1970 (1974).

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Mountain, R. D., *Single particle motions in liquids: Qualitative features of memory functions,* J. Res. NBS (U.S.) **78A,** 413 (1974).

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Collaborations With Outside Groups

Lester Haar of the Heat Division discusses the development of a high temperature equation of state with Gordon Powell, a guest worker of the division.

The opportunity for collaborative work with NBS scientists can provide a means whereby the scientists and engineers of other institutions can interact and utilize directly the special expertise and capabilities of NBS scientists and NBS facilities. A list of the institutions and subjects of some of the current and recent collaborations with the Heat Division is given here to indicate their scope.

Energy Research and Development Administration, the Office of Standard Reference Data (NBS), and NBS-Boulder (Cryogenics Division): The measurement and analysis of the thermodynamic properties of ethylene, a substance that ranks fourth in quantity among all chemicals produced in the United States.

College of American Pathologists, the National Committee for Clinical Laboratory Standards, the American Association for the Advancement of Medical Instrumentation, and other medical organizations: Provide assistance with the problems of standardization in medical thermometry.

Carnegie Institute, Pittsburgh: Descriptions of binary fluids near their critical points.

Australian Department of Defense Materials Research Laboratories: Standardization of a new base-metal thermocouple, Nicrosil/Nisil.

Naval and Air Force Metrology Service: Development and construction of ultrasonic manometers to replace conventional manometers.

Lockheed Scientific Laboratory: Studies of pion scattering of Ho at 0.1 K at the Los Alamos Meson Physics Facility in New Mexico.

University of Pennsylvania: Study of the superconducting properties of the metallic polymer $(SN)_x$.

University of Maryland and Temple University: Studies for extending the scaling law description of the critical region of fluids.

National Physical Laboratory, England: Study of absolute radiometric thermometry.

Energy Research & Development Administration: Computer simulation of the properties of bulk matter.

National Aeronautics and Space Administration: Evaluation of sensors for atmospheric studies.

Australian National Measurement Laboratory: Study of low temperature thermometer stability.

National Institutes of Health: Study of thin-film thermometry.

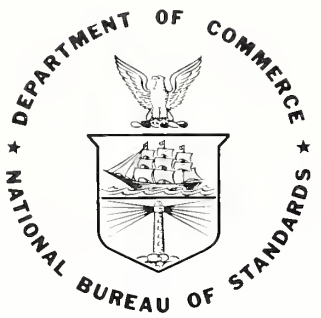
Naval Weapons Laboratory: Consultation on sonic measurements in liquid propellants.

Army Medical Research: Construction of humidity and temperature environmental chambers for microbiological growth studies.

University of Karlsruhe, Germany: Development of a calorimetric gas thermometer.

Picatinny Arsenal, Dover, N.J., and the Massachusetts Institute of Technology: Computer simulation studies of the microscopic behavior of shocked solids.

U.S. Army Missile Command: Development of portable pressure transducers in the high-pressure range to replace piston gauge standards.



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